Sudan University of Science and Technology

College of Graduate Studies

Title:

Modeling and Cost Assessment of FAC-19 Boat Deck Mold Using Reverse Engineering Techniques

نمذجة وتقييم التكلفة لقالب إنتاج سطح القارب FAC-19 بإستخدام تقنيات الهندسة العكسية

A Thesis Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements of the Degree of Master of Science in Mechanical Engineering (Production)

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QURANIC VERSE آية قرآنية

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

قال تعالي :(اللَّهُ الَّذِي خَلَقَ السَّمَاوَاتِ وَالْأَرْضَ وَأَنْزَلَ مِنَ السَّمَاءِ مَاءً فَأَخْرَجَ بِهِ مِنَ الثَّمَرَاتِ رِزْقًا لَكُمْ ۖ وَسَخَّرَ لَكُمُ الْفُلْكَ لِتَجْرِيَ فِي الْبَحْرِ بِأَمْرِهِ ۖ وَسَخَّرَ لَكُمُ الْأَنْهَارَ ﴿٣٢﴾ سورة ابراهيم.

Allah says : (It is Allah who created the heavens and the earth and sent down rain from the sky and produced thereby some fruits as provision for you and subjected for you the ships to sail through the sea by His command and subjected for you the rivers) Chapter (14) sūrat ib'rāhīm (Abraham).

DEDICATION

I dedicate my MSc thesis work to my family and many friends, a special feeling of gratitude to my loving parents, I dedicate this fulfillment research to the pure and noble soul of my mother, who spent the nights educating us and providing a decent life, and I ask God for her forgiveness, mercy and paradise.

I also dedicate this research for colleagues in the marine industries sector of the Sudanese Defense Industries System, and in particular Colonel Osama M. Abdul Rahim the Founder of the marine industry sector Who worked in extreme circumstances to localize the boat industry for the naval forces in Sudan and my colleague dr. Mohamed Hussein, whose words of encouragement and push for tenacity ring in my ears and supported me throughout the process. I will always appreciate all they have done.

I also dedicate this work to the brothers in the Sudanese Navy, and I hope that this research will be useful to them

I dedicate this work and give special thanks to my wife and my best friend engineer Mohamed Salah, Both of you have been my best cheerleaders.

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I would like to acknowledge and thank College of Graduate Studies at Sudan University of Science And Technology for allowing me to conduct my MSc program and providing any assistance requested. Special thanks go to the members of staff production engineering department for their continued support.

Finally I would like to thank the beginning teachers, mentor-teachers and administrators in our school division that assisted me with this project. Their excitement and willingness to provide feedback made the completion of this research an enjoyable experience.

Author

ABSTRACT

In this work, a multidisciplinary experience aimed to study how to obtain the 3D model of the upper part (Deck) for fast attack craft FAC-19, designed by Navirex design office in Genova – Italy (This type of craft Used in the Sudanese Navy) and Making a comparison between mold manufacturing techniques in term of cost. The reverse engineering process performed through convert PDF files to DWG format using AutoCAD 2017 software, and a 3D modeling step by the well-known 3D computer graphics software Rhinoceros. The reverse engineering model will be checked through manual measurement tools. The project includes comparison in terms of the basic materials costs used for manufacturing a temporary mold and a permanent mold for the deck model, and that after making designs for the molds similar to designs seen in one of the marine factories and according to the recommendations of references in this field, to choose the appropriate mold building technique depending on the number of products required and cost. The results gave insights concerning of the possibility of re-modeling identical FAC-19 boat deck to the product used in Sudanese navy, it also showed that the cost of materials needed to manufacture a permanent mold is nearly five times greater than the cost of materials needed to manufacture a temporary mold. The study recommended re-design and modeling of all boats available to the Sudanese Navy in order to settle the boat industry in Sudan. The study also recommends performing an analysis for the molds structures that were designed in this research to ensure their readiness and ability to be used in the production of FAC-19 boat deck.

ABSTRACT IN ARABIC

المستخلص

يهدف هذا البحث إلى دراسة امكانية الحصول على نموذج ثلاثي الأبعاد من ملف بصيغة **PDF** للجزء العلوي لقارب الهجوم السريع من نوع **FAC-19**، المستخدم لدى القوات البحرية السودانية والذي تم تصميمه بمكتب **NAVIREX** بمدينة جينوا في ايطاليا, وإجراء مقارنة بين الطرق المستخدمة في صناعة القوالب له من حيث تكلفة المواد الخام الاساسية لصناعتها. مع اخذ هذا القارب كتطبيق. تم إستخدام عمليات الهندسة العكسية من خلال تحويل ملفات **PDF** إلى تنسيق **DWG** بإستخدام برنامج **AutoCAD 2017**، وخطوة النمذجة ثلاثية الأبعاد بواسطة برنامج رسومات الكمبيوتر ثلاثي الأبعاد المعروف باسم **Rhinoceros** , تم فحص نموذج الهندسة العكسية من خلال أدوات القياس اليدوية حيث يلزم الاتصال المباشر مع المنتج المراد المعايرة عليه. يتضمن المشروع مقارنة تكلفة المواد الأساسية المستخدمة في بناء قالب مؤقت وقالب دائم للجزء العلوي للقارب **FAC-19** , وذلك بعد عمل تصميمات للقوالب شبيهة بتصميمات أحد مصانع القوارب العالمية وحسب التوصيات من الكتب و المراجع في هذا المجال ، لإختيار طريقة البناء المناسبة للمنموذج **FAC-19** من حيث عدد المنتجات المطلوبة وتكلفة المواد المستخدمة في انتاج القوالب, أعطت النتائج رؤى فيما يتعلق بإمكانية إعادة نمذجة الجزء العلوي للقارب **FAC-19** متطابق مع المنتج المستخدم في القوات البحرية السودانية ، كما أظهرت أن تكلفة المواد اللازمة لبناء قالب دائم أكبر بخمس مرات تقريبًا من تكلفة المواد اللازمة لبناء قالب مؤقت. اوصت الدراسة بإعادة التصميم ونمذجة كل القوارب المتوفرة لدى القوات البحرية السودانية بغرض توطين صناعة القوارب في السوادان, كما اوصلت الدراسة ان يتم عمل تحليل لهياكل القوالب التي تم تصميمها في هذا البحث للتأكد من جاهزيتها و قدرتها لإستخدامها في انتاج الجزء العلوي للقارب **FAC-19** .

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Chapter 1: INTRODUCTION

1.1. General Introduction:

There are many reasons for performing reverse engineering in various fields. Reverse engineering has its origins in the analysis of hardware for commercial or military advantage.

In this work, a multidisciplinary experience aimed to study how to obtain the 3D model of the upper part ((Deck) a deck is a permanent covering over a compartment or a hull of a ship. On a boat or ship, the primary or upper deck is the horizontal structure that forms the "roof" of the hull, (Edwards, 1988)) for fast attack craft FAC 19, designed by Navirex design office in Genova – Italy and Making a comparison between mold manufacturing methods in term of cost .

The reverse engineering process will performed through convert PDF files to DWG format using AutoCAD 2017 software , that has allowed to obtain very accurate measures of the deck , and a 3D modeling step by the well-known 3D computer graphics software Rhinoceros. The reverse engineering model will be checked through manual measurement tools were a direct contact with the boat is needed, this kind of method even if not more expensive and rather flexible.

1.2.Research Problem:

Owning military boats in the Sudanese Navy is through the import and purchase of ready-made boats, after the use of boat by navy always there is a desire to change some of the specifications Related to the interior area of the boat or the type of armament used in the boat, which need to change in the dimension or in the lamination (structure) of fiberglass, In most cases the changes needed are at the top of the boat or the deck part.

1.3.Research Importance:

The importance of research is to find a way to own 3D models for the fiberglass boats used in the Sudanese navy that there drawings are available in PDF format and the projection views are sufficient to make the 3D shape without taking additional measurement from the real product.

By this way it's possible to own several designs especially that many general layout design for boats deck are available on the internet, which can help to take advantage of previous designs to make a new design.

also choosing mold manufacturing method after comparison between the different methods in term of cost make the decision of which mold building method to use is one and only.

Knowing how to modify an existing design of the boat to suit new requirements makes it easier to modify existing boats rather than buying or producing a new boat.

1.4. Objectives:

- Re-Design and modeling of FAC 19 boat deck.
- Choosing the best mold building technique in term of cost for FAC 19 boat Deck

1.5.Research Methodology:

- Using AutoCAD and Rhinoceros software's to obtain the outer surfaces of the FAC 19 deck.
- Comparison between mold building techniques in term of cost.

1.6.Research Layout:

This thesis will be about redesign, modeling and cost verification of FAC-19 boat deck mold building of FAC-19 boat deck through reverse engineering techniques, the purpose of it is to model the FAC 19 boat deck by using AutoCAD and Rhinoceros as will be described in chapter 3, choosing a technique for Deck mold building by comparing the cost of two techniques in chapter 4.

At the end of thesis the results and conclusions will Confirm or deny the possibility of achieving the objectives of this research

Chapter 2: THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1.Preface

Few studies have been conducted directly to reverse Engineering in patrol boat manufacturing and optimizations are available; this part of thesis will define the composite material origins, the types of composite materials have been used in patrol boat manufacturing and marine industries also will give a brief about boats productions methods,

The origins of composite material concepts date back to the builders of primitive mud and straw huts. Modern day composite materials were launched with phenolic resins at the turn of the century. The start of fiberglass boatbuilding began after World War II. The U.S. Navy built a class of 28-foot personnel craft just after the war based on the potential for reduced maintenance and production costs. (Scott, 1996) .

According to **Greene** (1990) the use of Fiberglass Reinforced Plastic (FRP) has increased recently in marine structures with a minimum of engineering analysis and design evolution. Although fiberglass has been used for many years in small recreational and high-performance boats, a range of new composite materials are now being utilized for various applications.

2.2.Fiberglass reinforced plastic in boatbuilding

A fiberglass boat is a composite structure, made of many layers of various reinforcing fabrics and core materials, bonded together with plastic resins. You could also look at it as a plastic resin shell reinforced with various fibers, or Fiber Reinforced Plastic (FRP). Most loads in the structure are carried by the fibers in the laminate. Resin and core materials support the fibers in positions to effectively carry and spread the loads. Generally the higher the proportion of fiber to resin in a laminate, the greater its strength and stiffness, (Gougeon Brothers, Inc., 2014)

Figure 2-1 shows the 19.2 meter long composite patrol boat used by Sudanese Navy at the first trail test during 2015.

Figure 2-1, FAC19 patrol boat at the first trail test 2015 by Sudanese Navy

2.2.1. Composite material

In this section the general theory of composite material – its constituents, composition, properties and the production methods used in marine application will be described briefly.

They are three broad groups of composite materials (Eric Greene Associates, 1999):

- Reinforcements (Fiber);
- Resins (Matrix); and
- Core Materials.

2.2.1.1. Fiber: Types and Properties

Reinforcements for marine composite structures are primarily E-glass due to its cost for strength and workability characteristics, In general, carbon, aramid fibers and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency (Eric Greene Associates, 1999).

The fibers come in veil mat, short fibers mat, woven cloth, unidirectional tape, biaxial cloth or tri-axial cloth, the weight ratio of fibers to resin can range from 20% fibers to 80% resin to 70% fibers to 30% resin. (performance composites Inc, 2019).

The following table (2-1) comparing the relative properties of reinforcing fabrics, the comparison manly between fiberglass reinforcement fabric and carbon fabric.

Table 2-1, comparing the relative properties of reinforcing fabrics (www.fibreglast.com)

Specifications	Fiberglass	Carbon
Density	Poor	Excellent
Tensile Strength	Fair	Excellent
Compressive Strength	Good	Excellent
Stiffness	Fair	Excellent
Fatigue Resistance	Good-Excellent	Good
Abrasion Resistance	Fair	Fair
Sanding/Machining	Excellent	Excellent
Conductivity	Poor	Excellent
Heat Resistance	Excellent	Excellent
Moisture Resistance	Good	Good
Resin Compatibility	Excellent	Excellent
Cost	Excellent	Poor

2.2.1.2. Matrix: Types and Properties

The matrix used in structural composite materials is often polymer. Polymer is an umbrella term for materials which molecules are long chains of smaller structural units.

One way of grouping polymers is to divide them into thermoplastics and thermosets. Thermoplastics are characterized by their ability to solidify and re-melt, while thermosets cannot be re-melted upon solidification.

Due to their superior mechanical properties, thermosets are often used in structural composites. Thermosets are also simple to process in terms of temperature and pressure. Some thermosets used in composite applications are listed in Table 2-2 together with their properties. (Djurberg, 2012).

Table 2-2, Properties of thermoset matrices used in composite applications.

Polymer	Advantages	Disadvantages	Fiber
Unsaturated polyester	▪Low price ▪ Easy to process (high viscosity and simple crosslinking requirements) ▪ Good mechanical properties	▪ If untreated poor temperature and UV-light resistance ▪ Unhealthy work environment ▪ Shrinks when solidifying ▪ High water absorption	E-glass, S-glass
Epoxy	▪ Very good mechanical properties ▪ Good adhering properties ▪ Low shrinking ▪ Moisture resistance	▪Costly ▪Toxicity ▪Complicated process environment	Carbon, aramid, glass

Polymer	Advantages	Disadvantages	Fiber
Vinylester	▪ Performance in between UP and epoxy ▪ Same processing as for UP ▪ Moisture resistant	▪Performance in between UP and epoxy	E-glass, S-glass, carbon, aramid

2.2.1.3. Core Materials

Core materials form the basis for sandwich composite structures, which clearly have advantages in marine construction. A core is any material that can physically separate strong, laminated skins and transmit shearing forces across the sandwich. Core materials range from natural species, such as balsa and plywood, to highly engineered honeycomb or foam structures. The dynamic behavior of a composite structure is integrally related to the characteristics of the core material used. (Eric Greene Associates, 1999).

Core materials used in FAC 19 Deck according to the design documents are PVC foam (AIREX C70.55).

Foam cores were more commonly used in hull construction only however, recent developments have produced some excellent PVC foams that can be successfully used in deck structures. Better known brands include AIREX Tm and Core-Cell Tm. Manufactured in different densities, foam core can be used for most boat building applications. (Roberts-Goodson, 2008).

Table 2-3 shows the mechanical properties for AIREX C70 foam core.

Table 2-3, Mechanical properties for AIREX C70 foam core.

MECHANICAL PROPERTIES											
Typical properties for AIREX® C70		Unit (metric)	Value 1)	C70.40	C70.48	C70.55	C70.75	C70.90	C70.130	C70.200	C70.250
Density	ISO 845	kg/m^3	Average *Typ. range*	40	48 *43 - 55*	60 *54 - 69*	80 *72 - 92*	100 *90 - 115*	130 *120 - 150*	200 *180 - 250*	250 *225 - 288*
Compressive strength perpendicular to the plane	ISO 844	N/mm^2	Average *Minimum*	0.45	0.60 *0.50*	0.90 *0.75*	1.45 *1.10*	2.0 *1.7*	3.0 *2.6*	5.2 *4.5*	6.6 *5.3*
Compressive modulus perpendicular to the plane	DIN 53421	N/mm^2	Average *Minimum*	41	48 *35*	69 *55*	104 *80*	130 *110*	170 *145*	280 *240*	350 *280*
Tensile strength in the plane	ISO 527 1-2	N/mm^2	Average *Minimum*	0.70	0.95 *0.8*	1.3 *1.0*	2.0 *1.6*	2.7 *2.2*	4.0 *3.0*	6.0 *4.8*	7.5 *5.5*
Tensile modulus in the plane	ISO 527 1-2	N/mm^2	Average *Minimum*	28	35 *28*	45 *35*	66 *50*	84 *65*	115 *95*	175 *140*	230 *160*
Shear strength	ISO 1922	N/mm^2	Average *Minimum*	0.45	0.55 *0.50*	0.85 *0.70*	1.2 *1.0*	1.7 *1.4*	2.4 *2.1*	3.5 *3.2*	4.7 *3.8*
Shear modulus	ASTM C393	N/mm^2	Average *Minimum*	13	16 *14*	22 *18*	30 *24*	40 *34*	54 *45*	75 *68*	95 *78*
Shear elongation at break	ISO 1922	%	Average *Minimum*	8	10 *8*	16 *10*	18 *10*	23 *12*	30 *20*	30 *20*	30 *20*
Thermal conductivity at room temperature	ISO 8301	W/m.K	Average	0.031	0.031	0.031	0.033	0.035	0.039	0.048	0.056
Standard sheet	Width	mm ± 5		1330	1270	1150	1020	950	850	750	700
	Length	mm ± 5		2850 2)	2730 2)	2450 2)	2180	2050	1900	1600	1500
	Thickness	mm ± 0.5		5 to 80	5 to 70	5 to 70	3 to 68	3 to 60	5 to 50	5 to 40	5 to 40
Color				ligth green	violet	yellow	green	red	blue	brown	green

2.2.2. Production method brief

Below is a brief description of the methods used to produce composite parts: hand lay-up and vacuum assisted resin transfer molding, and a short summary of the production of a composite deck.

2.2.2.1. Hand lay-up

In this process, liquid resin is applied to the mold and then reinforcement is placed on top. A roller is used to impregnate the fiber with the resin. Another resin and reinforcement layer is applied until a desired thickness builds up. A roller is used to squeeze out excess resin and create uniform distribution of the resin throughout the surface. By the squeezing action of the roller, homogeneous fiber wetting is obtained. The part is then cured mostly at room temperature and, once solidified; it is removed from the mold (Mazumdar, 2002), figure 2-2 show the Hand Lay Up process.

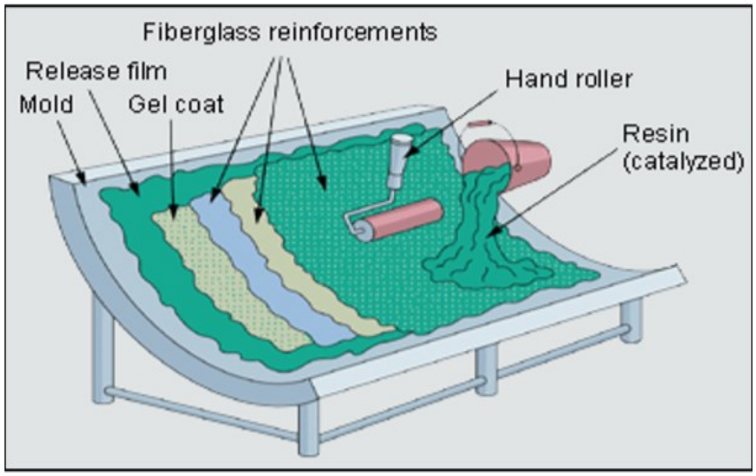


Figure 2-2, Hand Lay Up process

2.2.2.2. Vacuum assisted resin transfer molding

Vacuum assisted resin transfer molding (VARTM) is an effective way of producing large, continuous components in small series. The reinforcement is put into/onto a mold and is covered by a vacuum bag. Resin is then injected and impregnates the fibers due to the under pressure created by the vacuum (Figure 2-3). This method can be used to produce both single skin and sandwich panels and large parts of the boat. (Djurberg, 2012)

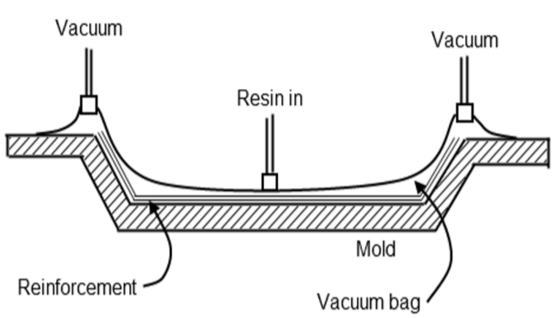


Figure 2-3, the principle of VARTM.

2.2.2.3. Production of a composite Deck

Briefly the mold surface is prepared by polishing to whatever degree of surface finish is requiring, then a Release Agent is applied. The next step is to apply a resin rich surface (Gelcoat). After this install the inner laminate, the inner laminate will consist of a varying number of layers of mat and roving or biaxial. The number of layers will depend on the type and size of the boat however the laminate should be clearly shown in building plans, and then follow the plans to finish. Table 2-4 shows the FAC-19 deck lamination plan.

Table 2-4, FAC 19 deck lamination plan

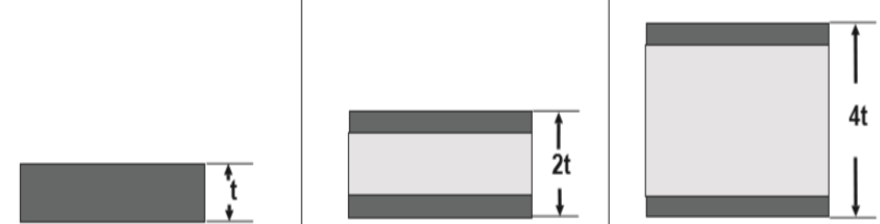
LAYER N°	MATERIAL	ORIENT.	% REINF. (weight) - Wf -	LAYER WEIGHT (g/m2)	THICKNESS (mm)	DECK
0	GELCOAT	/	/	700	0.60	
1	MAT 300	/	30	1000	0.70	
2	MAT 300	/	30	1000	0.70	
3	BIAX 0/90 600 + MAT 225	0/90°	48	1719	1.07	
4	BIAX 0/90 600 + MAT 225	0/90°	48	1719	1.07	
5	Bonder	/	/	800	1.00	
6	Airex C70.55 60 kg/mc	/	/	1500	25.0	
6	Coremat 50 kg/mc	/	/	400	8.00	
7	BIAX 0/90 600 + MAT 225	0/90°	48	1719	1.07	
8	BIAX 0/90 600 + MAT 225	0/90°	48	1719	1.07	
9	BIAX 0/90 600 + MAT 225	0/90°	48	1719	1.07	
11	MAT 300	/	30	1000	0.70	

2.2.3. Basic laminate building

The term laminate refers to a multi-layered composite with individual sheets bonded together by pressure or heat. A sandwich composite is defined as a core material sandwiched between two laminated composite facings or skins. The two facings of a cored composite provide the required bending and in-plane shear stiffness and carry the axial, bending, and shear loads (Marshall, 1982).

2.2.3.1. Single Skin and Sandwich core

While single skin composite is a homogeneous laminate, a sandwich composite consists of two single skin laminates (referred to as faces) separated by a low density core. The main idea is that the physical separation of the stiff composite sheets increases the bending stiffness while maintaining a low weight. (Djurberg, 2012). Figure 2-4 shows the strength and stiffness for cored and single skin construction.



Relative Stiffness	100	700	3700
Relative Strength	100	350	925
Relative Weight	100	103	106

Figure 2-4, strength and stiffness for cored and solid construction [Hexcel, the basics on sandwich construction]

2.3. Pervious study

(PAOLA et al., 2017) Study the permanent deformations of the hull of a regatta sailing yacht is described. In particular, a procedure to compare two different surfaces of the hull of a small sailing yacht, designed and manufactured at the

University of Palermo, has been developed. The first one represents the original CAD model while the second one has been obtained by means of a reverse engineering approach. The reverse engineering process was performed through an automatic close-range photogrammetry survey that has allowed obtaining very accurate measures of the hull, and a 3D modeling step by the well-known 3D computer graphics software Rhinoceros. The reverse engineering model was checked through two different procedures implemented by the graphical algorithm editor Grasshopper. The first procedure has allowed comparing the photogrammetric measurements with the rebuilt surface, in order to verify if the reverse engineering process has led to reliable results. The second has been implementing to measure the deviations between the original CAD model and the rebuilt surface of the hull. This procedure has given the possibility to highlight any permanent deformation of the hull due to errors during the production phase or to excessive loads during its use. The obtained results have demonstrated that the developed procedure is very efficient

Chapter 3: RE-DESIGN AND MODELING OF FAC 19 BOAT DECK

3.1. Preface

In this part the reverse engineering process will performed on FAC 19 boat deck through convert PDF 2D file to DWG format using AutoCAD 2017 software , then this DWG file will be used to prepare a 3D wireframe on through AutoCAD 2017 software too.

The 3D modeling phase will be performed by the well-known 3D computer graphics software Rhinoceros. The reverse engineering model will be checked through manual measurement tools, by verifying the accuracy of the 3d FAC 19 boat deck model dimensions by applying physical measurements on Existing product and comparing it with the dimensions taken from the 3d model on Rhinoceros software

Also this chapter will give a brief about techniques to modeling FAC 19 Deck and Mold building techniques can be used.

3.2. 2D model phase and 3D wireframe preparation using AutoCAD

Prior to AutoCAD 2017, it was not possible to convert a PDF file to a DWG file using AutoCAD. PDF files could only be inserted as underlays (external references); the content could then be traced and scaled to known dimensions, if desired. With the release of AutoCAD 2017, using the PDFIMPORT command, it is now possible to import PDF content directly into AutoCAD drawings. Lines will become editable geometry and text will become editable text. The accuracy of the resultant AutoCAD content is largely dependent upon the quality of the original PDF, so results may vary. Additionally, PDF underlays in drawings created with previous AutoCAD releases can be converted into editable drawing geometry using the PDFIMPORT command, (Autodesk Support , 2019).

Above paragraph shows that's there is an accuracy limitation when converting PDF to DWG format depending of the quality of the original PDF, but still PDF drawing converted into editable drawing geometry, which mean it's possible to be edited to meet the desired dimension written on the PDF or taken for the real product.

AutoCAD 2017 added the capability of editing PDF files. From a practical point of view, this is viable only if the PDF was created by exporting a drawing file from AutoCAD or another CAD program. Yes, AutoCAD can edit a PDF that came from a Word document, for example, but you don't want to do that, (Fane, 2017).

3.2.1. 2D model phase:

Below will illustrate how to edit the FAC 19 boat Deck PDF file using AutoCAD 2017

To edit any PDF drawing, do this:

1. Open a new or existing drawing file.
2. On the Application menu, choose Import → PDF.
3. Press Enter.
4. Browse to and select the desired PDF file using the file dialog box that has appeared.
5. Click Open. The Import PDF dialog box appears.
6. Click OK.

Figure 3-1 shows The Import PDF dialog box with Preview for general layout of FAC 19 boat. Figure 3-2 show PDF FAC 19 model as editable drawing geometry (DWG) in AutoCAD 2017 software.

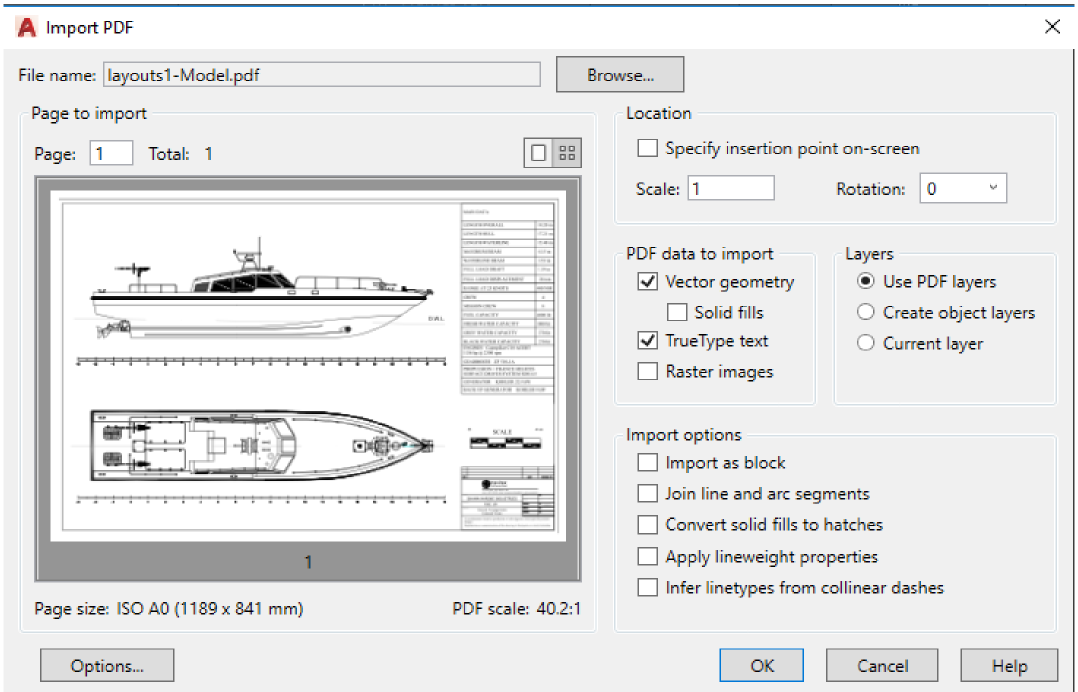


Figure 3-1, The Import PDF dialog box (Preview general layout of FAC 19 boat).

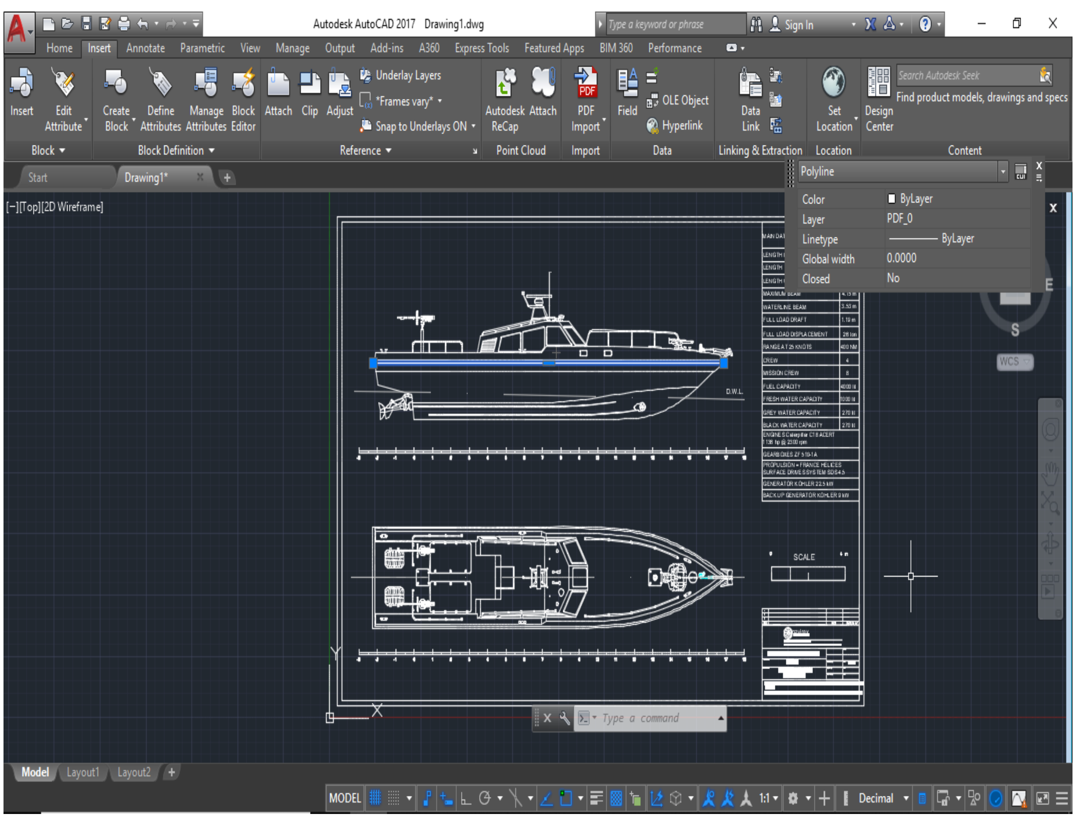


Figure 3-2, PDF FAC 19 model as editable drawing geometry (DWG).

After inspect the FAC 19 DWG drawing by taking dimensions for the overall length and maximum beam of the boat and compare them with dimension written on the PDF document, the accuracy result was quite good, table 3-1 show Compression between dimension from design Doc and converted PDF drawing to DWG, This comparison may not be sufficient to ensure the accuracy of all dimensions, but after drawing 3D FAC 19 models will be a more accurate comparison at FAC 19 deck 3D model dimensions assurance at the end of this chapter.

Table 3-1, Compression between dimension from design Doc and converted PDF drawing to DWG.

Checked length	**Length from design doc (m)**	**Length from DWG drawing with precision 0.0000 (m)**	**Length from DWG drawing with precision 0.00 (m)**
length overall	19.20	19.2019	19.20
maximum beam	4.15	4.1538	4.15

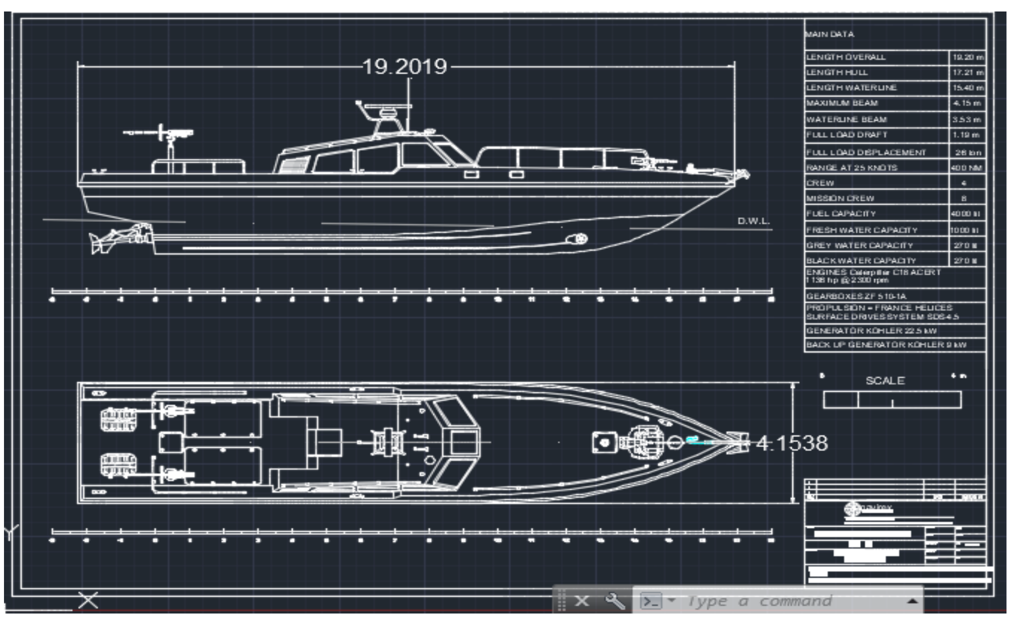


Figure 3-3, Length overall and maximum beam of FAC19 with precision 0.0000 (m)

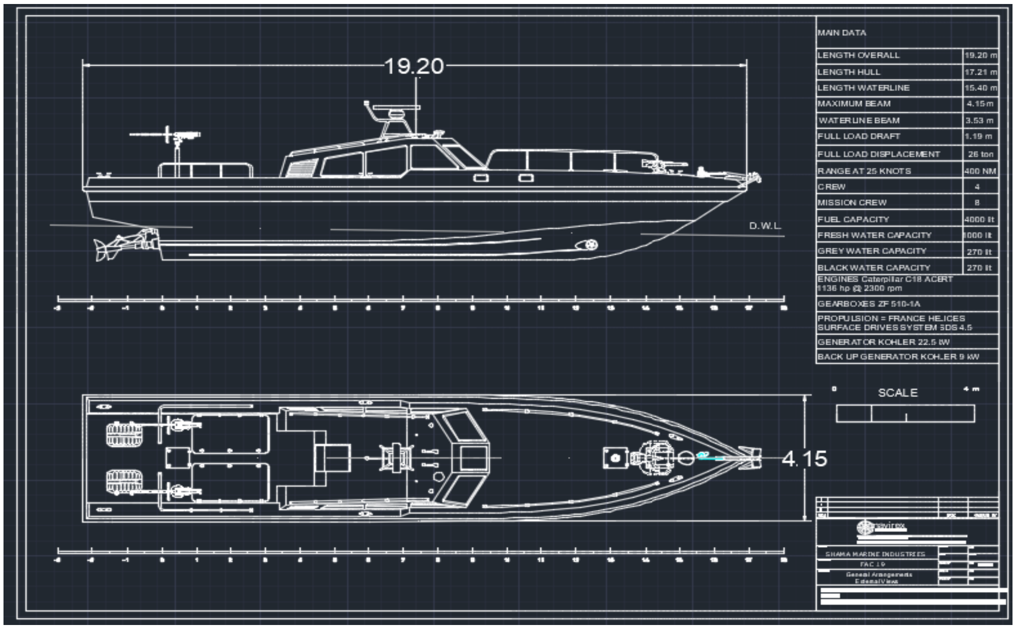


Figure 3-4, length overall and maximum beam of FAC19 with precision 0.00 (m).

3.2.2. 3D wireframe preparation using AutoCAD:

Now the layout model of the FAC19 is editable drawing and opened on the AutoCAD and sited on the right scale, with the use of command COPYPASE on the AutoCAD could easily put the front view and top view of boat in the new drawing page each in its origin viewport (see figure 3-5) and step by step can make the 3D wireframe with the help of AutoCAD commands for the above part of the boat (the Deck), as shown in figure 3-6.

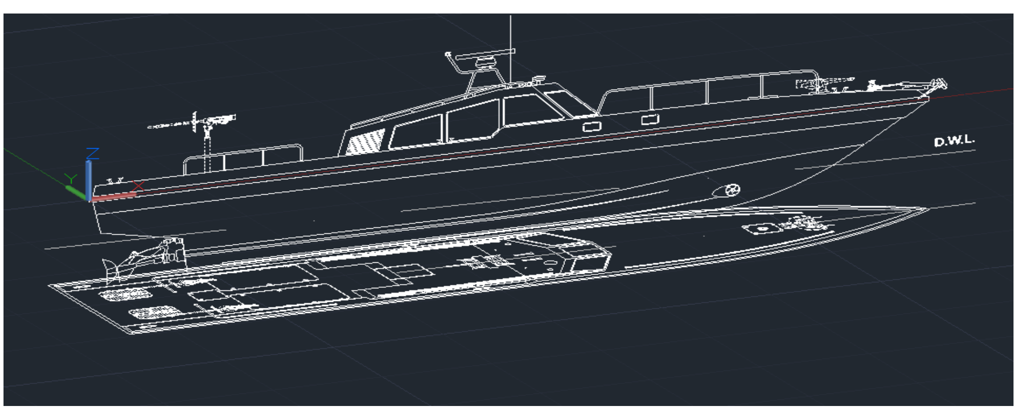


Figure 3-5, FAC 19 Front and top view perpendicular to each other.

The 3D wireframe executed to only the right half of the deck because the deck is symmetric and regardless the external accessories like the hand rails, anchor wench, radar mast and machine guns,…etc. which will be modeled in the 3D model phase using **Rhinoceros** software or downloaded ready from the internet.

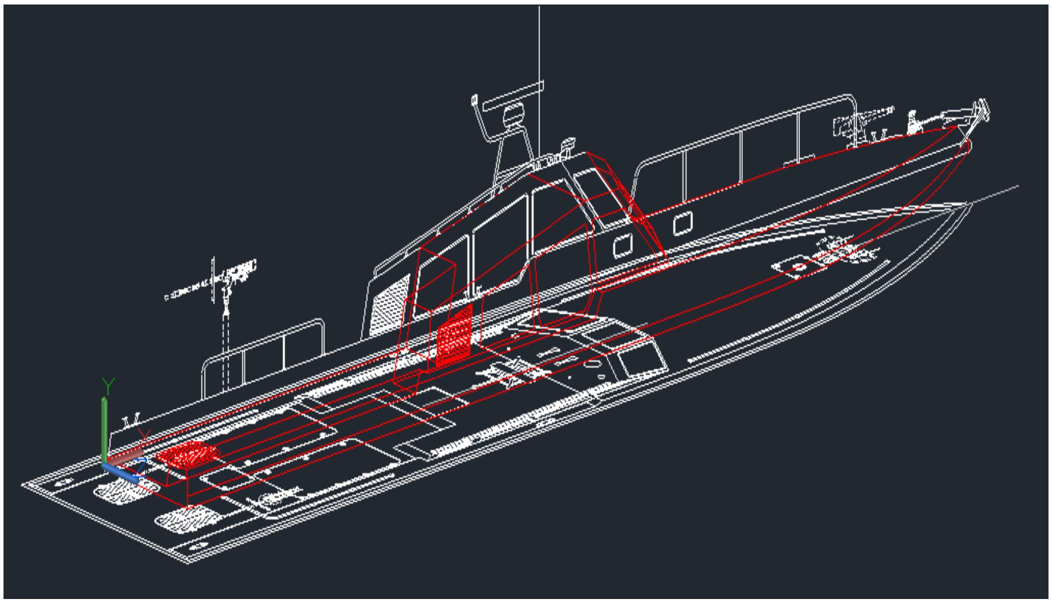


Figure 3-6, 3D wireframe for the right side of the FAC 19 Deck (red lines).

3.3. 3D model phase using Rhinoceros

Rhino can create, edit, analyze, document, render, animate, and translate Non-Uniform Rational B-Splines curves, surfaces, and solids, point clouds, and polygon meshes. There are no limits on complexity, degree, or size beyond those of your hardware. Surfaces can be created from 3 or 4 points, from 3 or 4 curves, from planar curves, from network of curves, rectangle, deformable plane, extrude, ribbon, rule, loft with tangency matching, developable, sweep along a path with edge matching, sweep along two rail curves with edge continuity, revolve, rail revolve, tween, blend, patch, drape, point grid, height field, fillet, chamfer, offset, plane through points, TrueType text, Unicode (double-byte) text. (Rhinocores , 2019). Figure 3-7 show the Surface tools command in Rhinoceros 5.

Figure 3-7, Surface tools command in Rhinoceros 5.

the DWG 3D wireframe for the right side of the FAC 19 Deck shown on the figure 3-6 will be open in Rhino software and start to make the outer surfaces of the deck using surface tools, and also will complete the 3D model in this program; figure 3-8 shows the DWG 3D wireframe for the right side of the FAC 19 Deck opened in Rhino, figure 3-9, 3-10 and 3-11 shows the modeling progress.

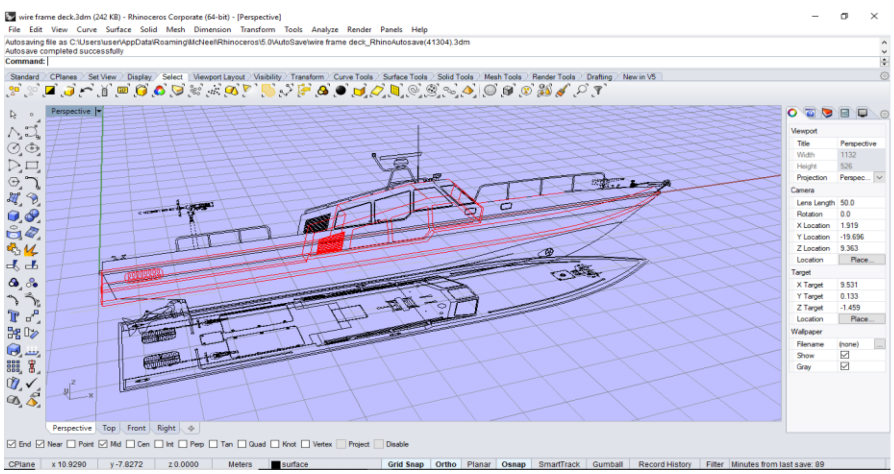


Figure 3-8, DWG 3D wireframe for the right side of the FAC 19 Deck opened in Rhino.

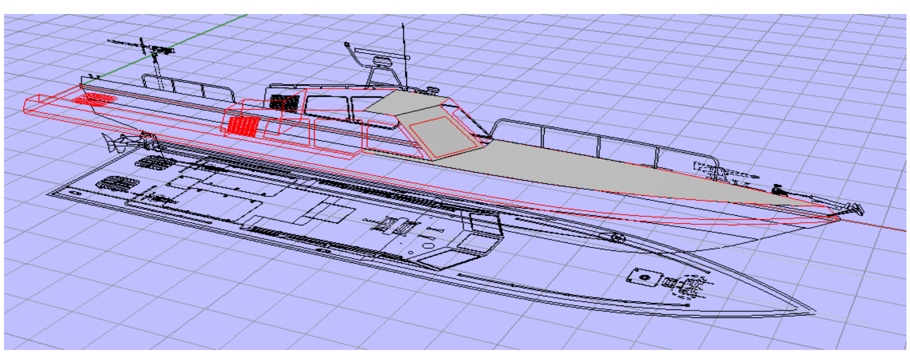


Figure 3-9, surfaces creation for FAC19 boat deck using Rhinoceros surface tools.

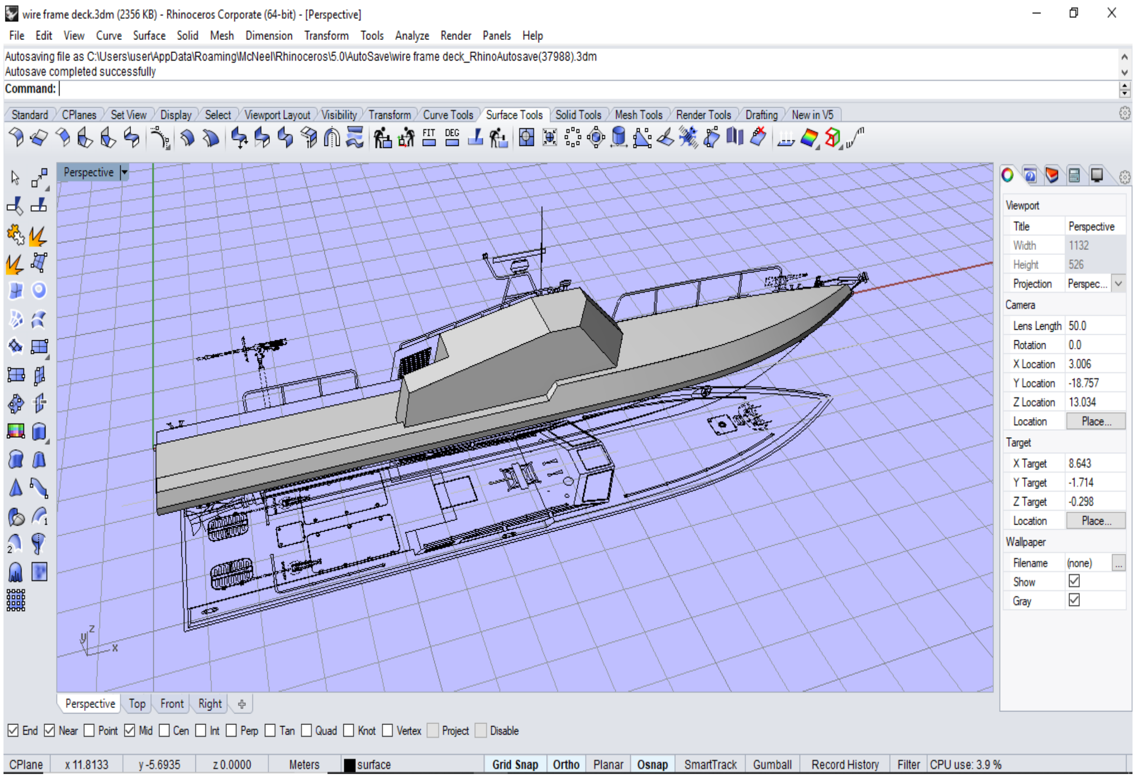


Figure 3-10, complete surfaces for the right side of the FAC 19 Deck

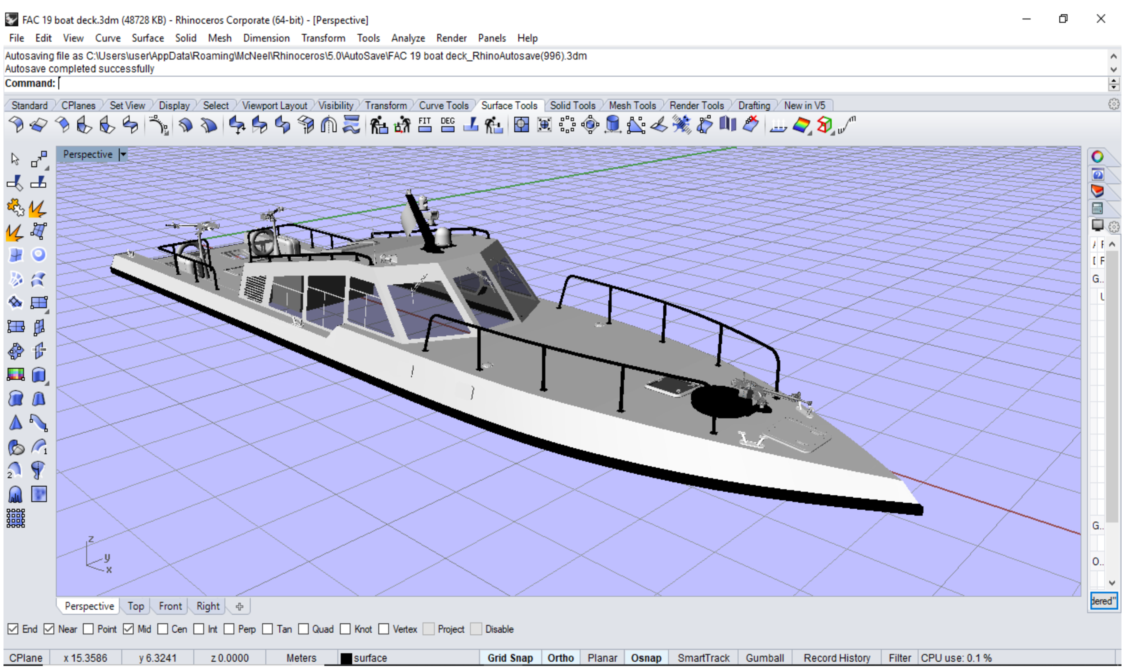


Figure 3-11, FAC19 boat deck complete model (hatches, machine guns, wipers and navigation equipment's downloaded ready from www.grabcad.com)

3.4.FAC 19 deck 3D model dimension assurance:

They are different methods for verifying the accuracy of a 3d model, Methods included physical measurements, digital photographic measurements, surface scanning, photogrammetry, and computed tomography (CT) scans.

The manual measurement tools (physical measurements) have been chosen to check the model dimension by taking measurements of the FAC 19 deck and comparing it with the model.

A random places on the model chosen and focus were at the bow (The bow is the forward part of the hull of a ship or boat (Jha, 2020)) in the place of Hull-Deck connecting curve and that By dividing the length of the boat into transverse sections, distance form each section to nearest one is 50 cm and then make measurements of the width of the selected sections and compare them with the same places on the existing product, also will check the angle between side window surface and the flat surface on the side of the deck and the width of the middle front glass. Figure 3-12 shows some of the dimension taken from the 3D model of the FAC 19 boat deck.

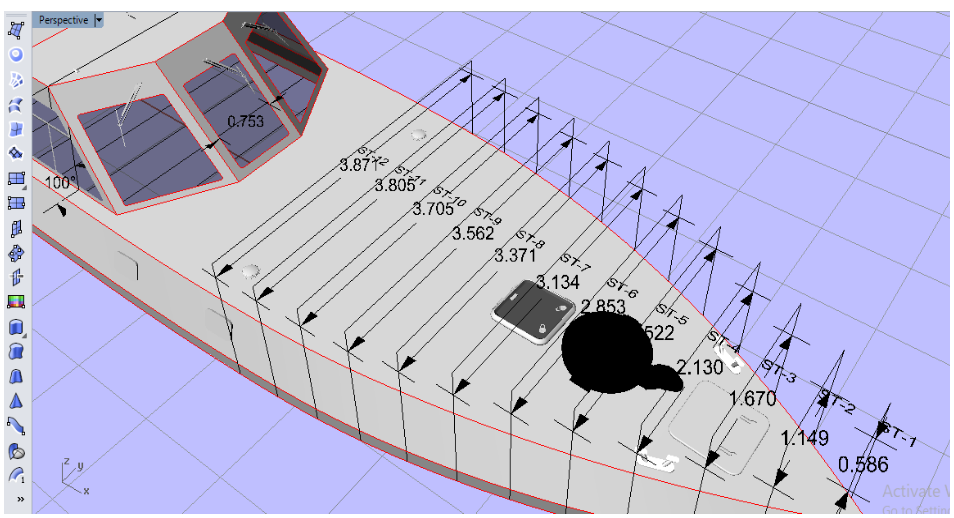


Figure 3-12, some of the dimension taken from the 3D model of FAC 19 boat deck

Emphasis has been placed on these dimensions, especially the dimensions at the front of the boat, because it is the most changing place in the dimensions which affect the assembly process between the hull and the deck of the boat.

Tabel 3-2 shows the compersion between selected diminesions of model and the exact places dimensions from on the exsiting product of FAC 19 boat deck.

Table 3-2, comparison between selected dimensions on the 3D model and existing product of FAC19 boat deck

Name of the Dimension	Dimension from 3D model with precision 0.000 (m)	Dimension from Existing Product with precision 0.000 (m)	Error %
ST-1	0.586	0.587	-0.17036
ST-2	1.149	1.150	-0.08696
ST-3	1.670	1.670	0
ST-4	2.130	2.130	0
ST-5	2.522	2.520	0.079365
ST-6	2.853	2.853	0
ST-7	3.134	3.135	-0.0319
ST-8	3.371	3.370	0.029674
ST-9	3.582	3.582	0
ST-10	3.705	3.705	0
ST-11	3.805	3.805	0
ST-12	3.871	3.870	0.02584
Side draft angel	100 °	100°	0
Front window width	0.753	0.750	0.4

And from the above table it is possible to note a percentage of conformity of the dimensions, its very high which makes us assure that the 3D model is identical to the real product, It is true that there are some differences in some dimensions, but they are in millimeters that may have resulted during manufacturing or during the manual measurement process.

With this comparison the model can be judged as valid for use in the production of molds that give good simulated results for FAC19 boat deck.

3.5. Mold building techniques used for FAC 19 deck.

Manley they are two techniques can be used to build a mold for the fiberglass boat the first one is a 3D machining for the entire mold , the second is by slicing techniques where the product is divided to frames and the frames assembled to form a plug which used to form a fiberglass mold (permanent mold) or the frames assembled to form a mold directly (temporary mold), in this study will focus on the second technique to avoid having a large CNC machine (the length of the FAC19 deck is 19 meter).

With the advent of Computer Assisted Design CAD and Computer lofting, it has become possible for the designer to supply the builder with very accurate full size patterns. Usually included with the full size patterns, are the frames, stem, expanded transom, deck beams, cabin top beams and miscellaneous other items, which can be made directly from these patterns. Having the personal knowledge of several thousand 18' to 70' [5.48 M to 21 M] boats being successfully built using full size patterns, I can say with absolute confidence that you should try to obtain a plan with full size patterns. You will save many frustrating man hours and the boat will be shaped as the designer intended it to be. (Roberts-Goodson, 2008). Full size patterns and lines plan can be obtained easily from the 3D model by making sections to the model where wanted.

Molds are made from the body plan, and because they are only temporary, they are made from lower grade lumber than that used for the boat parts. Any lumber except hardwood is suitable, when a number of boats are to be built alike it is advantageous to make a permanent mold, (Steward, 2011).

3.5.1. Female mold (by using a plug) permanent mold

In this technique a male plug should be make to be used to form a female fiberglass mold for FAC19 deck, The plug is an exact representation of the object to be fabricated, and one of the primary keys to success in mold construction is proper preparation of the plug. Any imperfections in the plug surface will be transferred to the mold, and then to future parts made from that mold, Plugs can be created from a variety of materials, as long as they are dimensionally stable. These materials commonly include wood, MDF, clay, foam and balsa

3.5.2. Female mold (without using a plug) temporary mold

Here no need to make a plug only a temporary female mold is made from wood.

In the next chapter a cost and quality comparison will be performed to compare between the permanent and temporary mold, figure 3-13 illustrate the male and female mold.

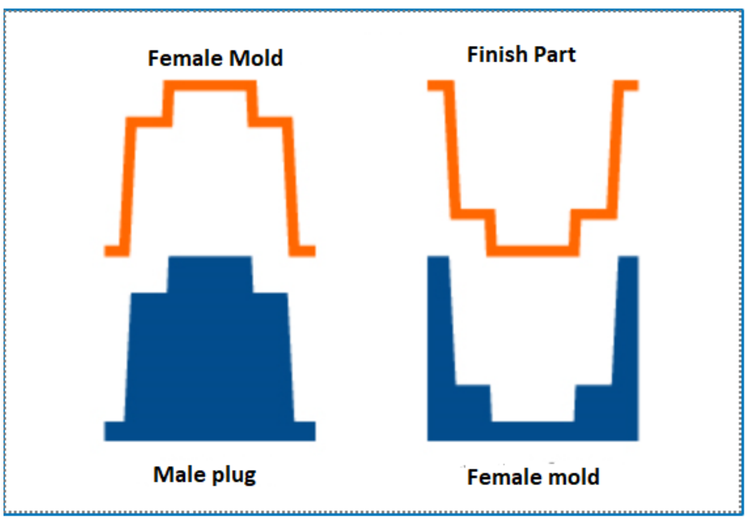


Figure 3-13, male and female mold

Chapter 4: FAC 19 BOAT DECK MOLD BEST BUILDING TECHNIQUE IN TERM OF COST

4.1. Preface

Designs and building techniques have changed but the mold remains the key to a fiberglass boat's construction, appearance, and performance (Frederiksen, 2017).

The costs of creating a temporary mold and a permanent mold for the deck model will be studied in terms of the costs of the basic materials used in the manufacturing each of them, and that after making designs for the molds similar to designs seen in one of the marine factories and according to the recommendations of references in this field, To choose the appropriate technique depending on the number of products required.

4.2.FAC 19 deck Mold building methods comparison

For study purposes, plywood will be used to create the plug and the temporary mold, the permanent mold will be created from the fiberglass.

Prior to the comparison operations, the quantities of plywood and fiberglass material needed for the plug and for the female mold will be calculated. The required quantities of plywood will be calculated after making a construction drawing that shows the details of the FAC19 deck plug and FAC19 temperoray femal mold.

The construction will be done by dividing the FAC 19 boat deck into longitudinal sections frames that are 50 cm away from each other and transverse sections frames located at a distance of 50 cm apart, and these sections will be made of plywood with a thickness of 18 mm and then covering these sections with panels of plywood with a thickness of 12 mm. This method of construction I've seen it in SHAMA Marine Industries in Egypt on a one of my work visit and they used this method for several years in the manufactureing of military boats and yachts with lengths of up to 30 meters.

Windows and hatches places on FAC 19 boat deck will be ignored when manufacturing mold and macking cutout for them on the product.

4.2.1. Permanent mold.

A mold is built over a plug that geometrically resembles the finished part. The plug is typically built of non-porous wood, such as oak, mahogany or ash. The wood is then covered with about three layers of 7.5 to 10 ounce cloth or equivalent thickness of mat. The surface is faired and finished with a surface curing resin, with pigment in the first coat to assist in obtaining a uniform surface (Eric Greene Associates, 1999).

4.2.1.1. Building a plug

To build a plug to for the permanent mold, begin by the frames of the plug and then these frames are erected in an inverted position on a solid foundation. When all framing is erected, the skeleton can be covered by plywood with 12 mm thickness that judged suitable to achieve the shape of the FAC 19 deck.

Frames will be obtained by tacking advantage of the avalability of the FAC19 deck 3D surfaces in Rhinoceros program and making intersections with these surfaces and extracting the shape of the frames tacking into account 14 mm clearance (12 for covering these frames and 2 mm for covering the wood by mat and fishing the surfaces fo the plug) in order the plug match the size of the finsh figure 4-1 shows places for longitudinal frames and transverse section frames, figure 4-2 illustrate the frames lines after apply the inside offset of 14 mm for all frames lines.

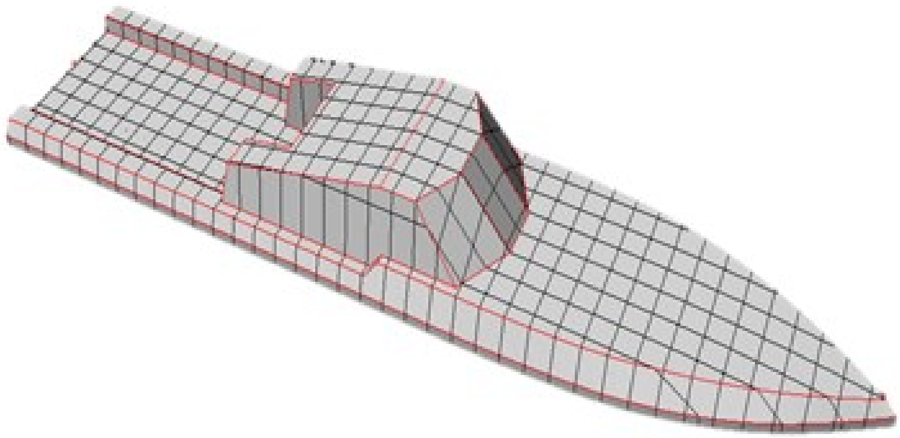


Figure 4-1, longitudinal and transverse section frames lines places

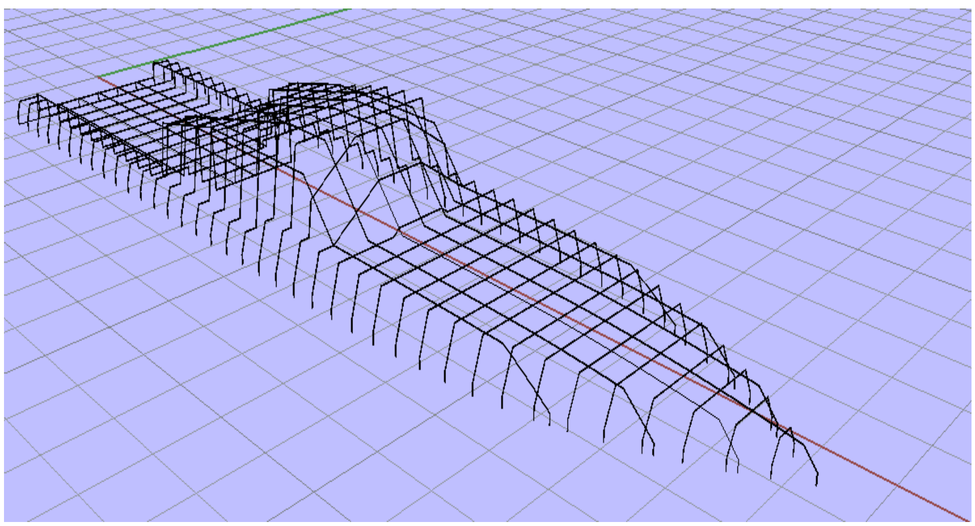


Figure 4-2, longitudinal and transverse section frames lines with inside offset 14 mm

Its Notably from figure 4-2, all frames are open polylines, it will be converted to closed polylines (regions) to be acceptable for cutting by CNC router and that by making an extension from the lowest points in the frames to a distance of 40 cm and then closed them with straight lines as shown in figure 4-3 , the increase in a distance of 40 cm for leaving a space to install the frames on a base and to make the plug high from the ground for ergonomic considerations to the carpenters when they assembling the covers over frames at the very low side of the plug.

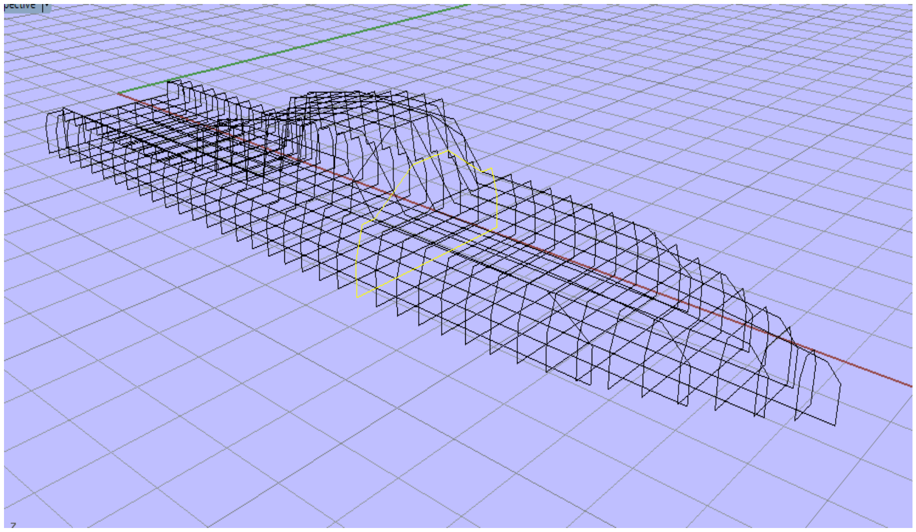


Figure 4-3, plug frames converted to regions.

After that the frames can be converted to solid parts with thickness of 18 mm as shown in figure 4-4 in order to calculate of the area of the frames and to visualize the connecting and joint methods of frames.

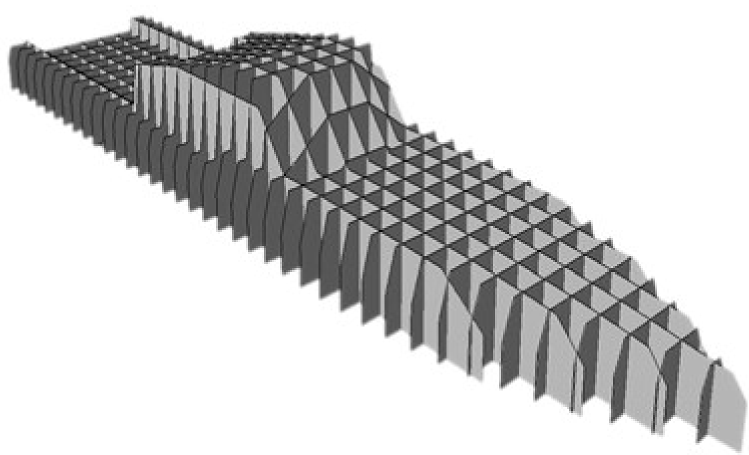


Figure 4-4, plug frames as solid parts

After the frames are erected on to the solid foundation and joint together the well by ready to be covered with 12 mm plywood as shown in figure 4-5.

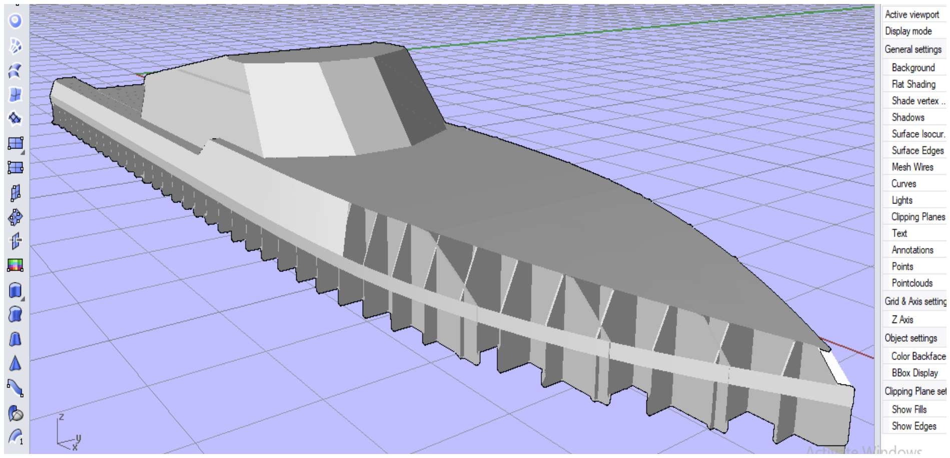


Figure 4-5, FAC 19 plug frames covering

Table 4-1 shows the area of plug frames calculated from Rhinoceros program (frames are numbered by ST/SL-n where ST for transverse section, SL for longitudinal section and n =1 to 38 starting by 1 from the bow (deck front) for transverse section and starting by 1 form the midsection for longitudinal sections.

Table 4-1, area of FAC19 plug longitudinal and transverse sections.

Section No	Area (m^2)	Section No	Area (m^2)	Section No	Area (m^2)
ST-1	0.407	ST-16	5.333	ST-31	2.398
ST-2	0.894	ST-17	6.875	ST-32	2.398
ST-3	1.390	ST-18	7.381	ST-33	2.398
ST-4	1.866	ST-19	7.38	ST-34	2.398
ST-5	2.304	ST-20	7.163	ST-35	2.398
ST-6	2.696	ST-21	6.908	ST-36	2.398
ST-7	3.044	ST-22	6.649	ST-37	2.398
ST-8	3.345	ST-23	6.388	ST-38	2.360
ST-9	3.580	ST-24	6.124	SL-1	20.103
ST-10	3.763	ST-25	3.840	SL-2	19.392
ST-11	3.897	ST-26	3.731	SL-3	19.332
ST-12	3.993	ST-27	2.531	SL-4	18.615

Section No	Area (m^2)	Section No	Area (m^2)	Section No	Area (m^2)
ST-13	4.066	ST-28	2.398	SL-2	19.392
ST-14	4.122	ST-29	2.398	SL-3	19.332
ST-15	4.253	ST-30	2.398	ST-4	18.615
		Total Plywood 18 mm Area			**275.044**

Thus, the total area needed of 18 mm Plywood for building plug frames without the amount of raw material waste has been calculated.

And also from Rhinoceros software the total area needed for the covering panel (12 mm plywood) it was calculated and the total area value was 101.723 m^2.

After covering the frames with 12 mm plywood now the plug is ready to be covered with about three layers of 7.5 to 10 ounce cloth or equivalent thickness of mat

According to (Lubin, 1982) a three layer of 10 ounce cloth will make up a thickness of 1.2 mm in hand lay up tekniques and according to deck lamination plan in table 2-4 one layer of mat will make up a thickness of 0.7 mm, so its acceptable to cover the wood by a two layer of mat 300 (1.4 mm thickness) and 0.6 mm by tooling gel coat after that the plug will be resimble the FAC 19 boat deck.

By that the basic materials used to produce the plug can be counted as follow:

Amount of 18 mm thickness plywood= Total Plywood 18 mm Area/ sheet size

= 275.044/ (2.44*1.22) =92.4 sheet ≈93 sheet.

Amout of 12 mm thickness plywood = Total Plywood 12 mm Area/ sheet size

= 101.723/(2.44*1.22)=34.2 sheet ≈ 35 sheet.

The amount of mat, resin and gel coat needed to cover the plug will be calculated to the total area of the plug (101.723 m^2)

Amount of mat (300 g/m^2) for 2 layer =0.3*101.723*2= 61 kg.

Amount of resin for 2 layer of mat 300=0.7*101.723*2=142.5 kg.

Amount of gel coat for 0.6 thickness =0.7*101.723=71.2 kg.

Note : (same fiber to resien ratio and gel coat weight and thickness in the deck lamination plan has been used at table 2-4 of deck lamination plan)

4.2.1.2. Building the permanent mold

According to (Eric Greene Associates, 1999) the first step of building a mold on a male plug consists of gel coat application, which is a critical step in the process. A non-pigmented gel coat that is specifically formulated for mold applications should be applied in 10 mil (0.254 mm) layers to a thickness of 30 to 40 mils (0.762 to 1.016 mm), the characteristics of tooling gel coats include: toughness, high heat distortion, high gloss and good glass retention. Aback-up layer of gel that is pigmented to a dark color is then applied to enable the laminator to detect air in the production laminates and evenly apply the production gel coat surfaces. After the gel coat layers have cured overnight, the back-up laminate can be applied, starting with a surfacing mat or veil to prevent print-through. Reinforcement layers can consist of either mat and cloth or mat and woven roving to a minimum thickness of 1/4 inch (6.35 mm). Additional thickness or coring can be used to stiffen large molds. Framing and other stiffeners are required to strengthen the overall mold and permit handling.

According to (McVeagh et al., 2010) some of the useful tips when making a mold are: Ensure that mold thickness is 6 mm thick for a boat up to 3 m in length then add 2-mm thickness for each meter of length and avoid print through by using no roving or core material closer than 6 mm from the gelcoat.

From above two paragraphs, the deck mold lamination plan can be made as shown in table 4-2 after detrmine the thickness of fiberglass mold of FAC 19 deck.

Thickness of the mold=6mm + (length of the FAC 19 deck -3)*2mm= 6 + (19.2-3)*2=38.4 mm.

Table 4-2, the FAC 19 deck mold lamination plan.

Layer No	material	Resin Qty (g/m^2)	Layer weight (g/m^2)	Thickness (mm)
0	Non-pigmented gel coat	-	933	0.8
1	Dark pigmented gel coat	-	700	0.6
2	MAT 300	700	1000	0.7
3	MAT 300	700	1000	0.7
4	MAT 300	700	1000	0.7
5	BIAX 0/90 600+ MAT 255	894	1719	1.07
6	BIAX 0/90 600+ MAT 255	894	1719	1.07
7	BIAX 0/90 600+ MAT 255	894	1719	1.07
8	BIAX 0/90 600+ MAT 255	894	1719	1.07
9	Bonder	-	800	1.0
10	Airex C70.55 60 kg/m^2	-	1500	25
11	BIAX 0/90 600+ MAT 255	894	1719	1.07
12	BIAX 0/90 600+ MAT 255	894	1719	1.07
13	BIAX 0/90 600+ MAT 255	894	1719	1.07
14	BIAX 0/90 600+ MAT 255	894	1719	1.07
15	MAT 300	700	1000	0.7
16	MAT 300	700	1000	0.7
17	MAT 300	700	1000	0.7
	Thickness external skin mm (between gel coat and bonder)			**6.38**
	Thickness internal skin mm (after core)			**6.38**
	Thickness lamination mm (without gel coat thickness)			**38.76**
	Total resin quantity for 1 m^2 laminate g/m^2			**11352**
	Total MAT 300 weight for 1 m^2 laminate g/m^2 =300*6			**1800**
	Total BIAX 0/90 600+ MAT 255 weight for 1 m^2 laminate			**6600**
	Total gel coat weight 1 m^2 g/m^2			**1633**

From above table, the deck mold lamination plan has met the requirement of mold thickness and the requirement of avoiding print through by using no roving or core material closer than 6 mm from the gelcoat. Table 4-3 shows the total amount of basic materials needed to build the Permanent mold of FAC 19 boat deck in term of wight/sheets to total area of the FAC 19 boat deck.

Table 4-3, Basic material quantities for permanent FAC 19 boat deck mold

	Material	**Qty (g/m^2)**	**Qty for 101.723 m^2 (kg/m^2 ,sheet) – Rounded**
Plug material	Marine Plywood 18 mm	**-**	**93 sheets**
	Marine Plywood 12 mm	**-**	**35 sheets**
	Gel coat	**700**	**72**
	MAT 300	**600**	**61**
	Resin	**1400**	**143**
Permanent mold material	Gel coat	**1633**	**167**
	MAT 300	**1800**	**184**
	BIAX 0/90 600+ MAT 255	**6600**	**672**
	Bonder	**800**	**82**
	Airex C70.55 60 kg/m^2	**1500**	**153**
	Resin	**11352**	**1155**

4.2.2. Temporary mold

Here the process is building a female mold dirctly from plywood, beginning with same steps of biulding the plug by the frames of the female mold and then these frames are erected in an inverted position on a solid foundation. When all framing is erected, the skeleton can be covered by plywood with 12 mm. figure 4-6 shows a sample of one-off female mold.

Figure 4-6, One-Off Female Mold (Eric Greene Associates, 1999)

Frames will be obtained by tacking advantage of the avalability of the FAC19 deck 3D surfaces in Rhinoceros as shown in figure 3-2.

The difference will be that the frams will be used to produce a female mold which means the skeleton of the frames will be oppsite than in the plug in order to contain the FAC 19 boat deck inside the female mold, also Clearance for frames covering (12 mm) will also be taken into consideration as shown in figure 4-7.

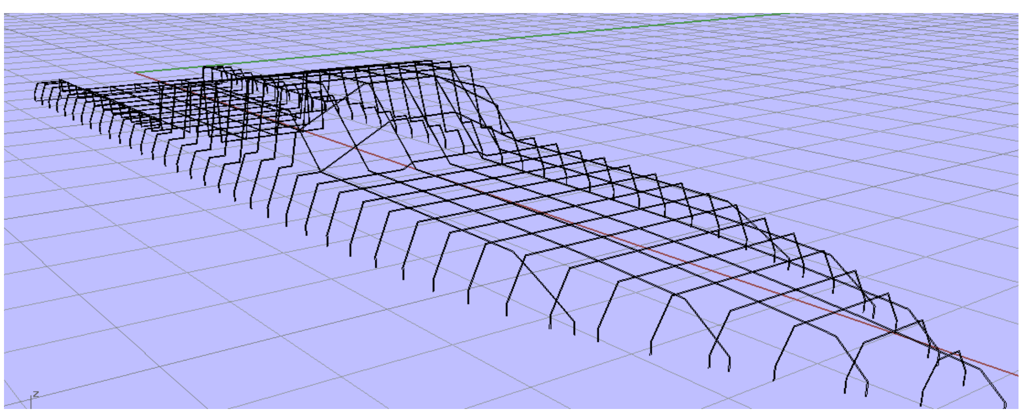


Figure 4-7, longitudinal and transverse section frames lines with outside offset of 12 mm here will not add adistance for finishing the surface of the female mold because its temporary and will be used to produce one product, The effort of finshing will be diverted to the product.

All frames are open polylines, it will be converted to closed polylines (regions) for Beginning of preparation for cutting by CNC router machine and that by making side extension for both end of the frames lines by a distance of 20 cm and then close the frames by U shape lines that lower than the lowest point in the frames by 40 cm for leaving a space to install the frames on a the solid base as shown in figure 4-8.

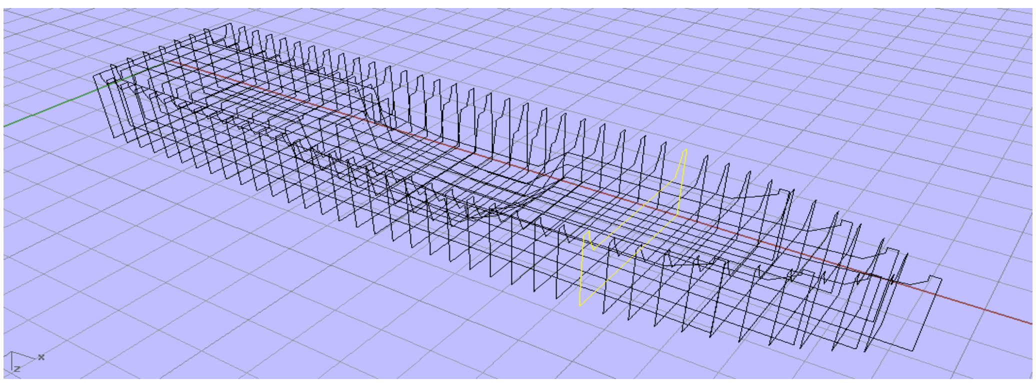


Figure 4-8, female frames converted to regions.

After that the frames will be converted to solid parts with thickness of 18 mm as shown in figure 4-9, and covered with 12 mm plywood as shown in figure 4-10.

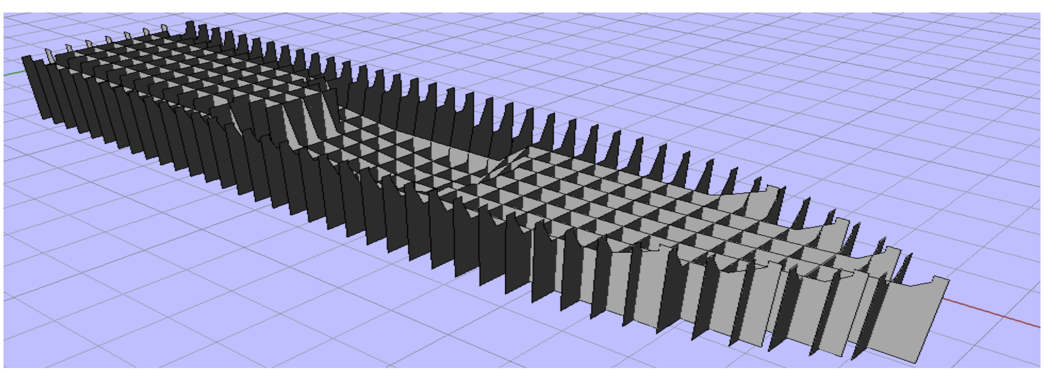


Figure 4-9, female mold frames as solid parts

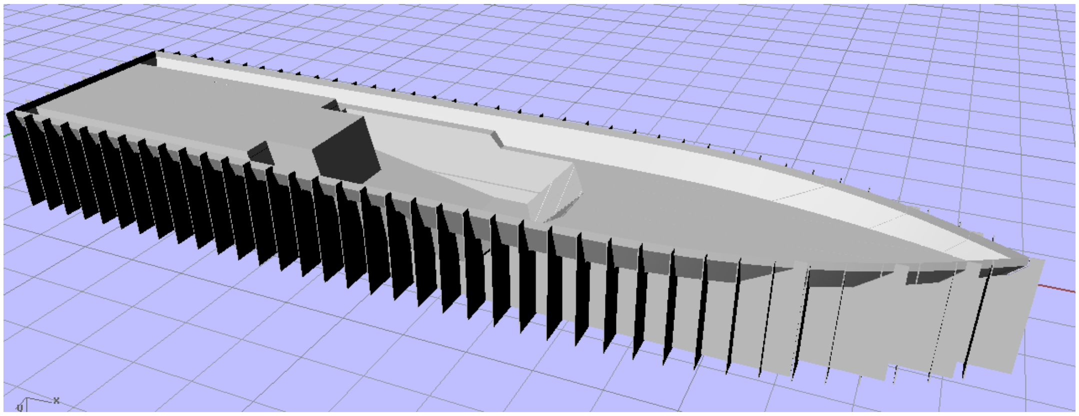


Figure 4-10, FAC 19 female mold frames covering.

Table 4-4 shows the area of female mold frames calculated from Rhinoceros program (frames are numbered by ST/SL-n where ST for transverse section, SL for longitudinal section and n =1 to 38 starting by 1 from the bow (deck front) for transverse section and starting by 1 form the midsection for longitudinal sections.

Table 4-4, area of FAC19 female mold longitudinal and transverse sections.

Section No	Area (m^2)	Section No	Area (m^2)	Section No	Area (m^2)
ST-1	1.959	ST-16	5.614	ST-31	8.566
ST-2	2.892	ST-17	4.067	ST-32	8.566
ST-3	3.709	ST-18	3.548	ST-33	8.566
ST-4	4.395	ST-19	3.548	ST-34	8.566
ST-5	4.943	ST-20	3.765	ST-35	8.566
ST-6	5.385	ST-21	4.024	ST-36	8.566
ST-7	5.746	ST-22	4.286	ST-37	8.566
ST-8	6.043	ST-23	4.55	ST-38	8.609
ST-9	6.289	ST-24	4.817	SL-1	28.868
ST-10	6.467	ST-25	7.052	SL-2	27.391
ST-11	6.582	ST-26	7.168	SL-3	24.966
ST-12	6.655	ST-27	8.433	SL-4	22.15

Section No	Area (m^2)	Section No	Area (m^2)	Section No	Area (m^2)
ST-13	6.706	ST-28	8.566	SL-2	27.391
ST-14	6.742	ST-29	8.566	SL-3	24.966
ST-15	6.669	ST-30	8.566	ST-4	22.15
		Total Plywood 18 mm Area			**414.205**

Thus, the total area needed of 18 mm Plywood for building the female mold frames without the amount of raw material waste has been calculated.

And also from Rhinoceros software the total area needed for the covering panel (12 mm plywood) it was calculated and the total area value was 101.723 m2, without taking in to account the material scrap raw material.

By that the basic materials used to produce the female mold can be counted as follow

Amount of 18 mm thickness plywood= Total Plywood 18 mm Area/ sheet size

= 414.205/ (2.44*1.22) =139.1sheet ≈140 sheet.

Amout of 12 mm thickness plywood = Total Plywood 12 mm Area/ sheet size

= 101.723/(2.44*1.22)=34.2 sheet ≈ 35 sheet.

4.2.3. Cost comparison

The cost of the permanent mold and the cost of the temporary mold will be calculated on the basis of the basic materials used to produce them. In the case of the permanent mold, the cost will be calculated on the basis of plywood, fiber, resin, and gel coat, while in the case of the temporary mold the cost of production materials will be calculated on the basis of plywood only.

Table 4-5 show the prices of plywood sheets, table 4-6 show the prices of fiber reinforcement, resin, gel coat and hardener.

Table 4-5, Marine plywood sheets cost. (woodworkers, 2020)

Updated on				9 May 2020
Material	Length (mm)	Width (mm)	Thickness (mm)	Price
General Marine plywood Malaysian -construction grade	2440	1220	12	€ 49.20
General Marine plywood Malaysian construction grade	2440	1220	18	€ 82.29

Table 4-6, fiberglass material cost (Faserverbundwerkstoffe, 2020)

N	**Type of material**	**Price €**	**Base price €/kg**
1	Mold Gel coat PREPREG bucket/ 5 kg	141.07	28.21
2	MAT 300 Chopped strand mat 300 g/m², 127 cm, roll/ 50 m	103.79	5.45
3	BIAX 0/90 600+ MAT 255, Roll 50 kg	348	6.96
4	Bonder	-	5.2
5	AIREX® Sheet C70.75 green (2000 x 500 x 25 mm) box/ 1 pc	146.08	97.4
6	Laminating Resin SYNOLITE 5690-P-1, barrel/ 220 kg	1,143.5	5.2
7	MEKP hardener, can/ 1 kg	21.48	21.48

According to (Roberts-Goodson, 2008) bonder (**RESIN PUTTY – FILLERS**) This do-it-yourself material can be made for a fraction of what you would pay if you bought it, There are several materials that can form the dry ingredients of the resin putty mixture. These include industrial talcum powder, Q-Cells and micro balloons, When mixed with waxed polyester resin and a small amount of additional accelerator they make and excellent and economic filler. You then add a dash of catalyst. This does not have to be measured, as you will soon gauge the mount required to make the bonder set in the desired time, Therefore, its price was considered equal to the price of the resin.

CATALYST – MEKP MEKP (Methyl Ethyl Ketone Peroxide) is normally a clear liquid commonly known as catalyst which must be handled with extreme care. Polyester resin will not harden without catalyst. The amount of catalyst added to the resin is critical and it is normally used in a ratio of 1-2% by weight of the total polyester resin. As a rule of thumb, 20mls of catalyst is usually needed for 1kg of resin. (Roberts-Goodson, 2008) , total quantity needed from MEKP will be determined by this rule.

Thus, all the cost of the basic materials used in the manufacture of the temporary and permanent molds is determined, and through it the total costs of the materials used in the manufacturing the FAC 19 boat deck molds can be calculated, table 4-7 shows the material cost of parmanent mold and table 4-8 show the cost of the basic material used for temperoray mold.

Table 4-7, Basic material cost for permanent FAC 19 boat deck mold

	Material	**Qty for FAC 19 deck (kg/m^2 ,sheet) Rounded**	**Base price €/kg- €/sheet**	**Total cost**
Plug material	Marine Plywood 18 mm	93 sheets	49.2	4575.6
	Marine Plywood 12 mm	35 sheets	82.29	2880.15
	Gel coat	72	28.21	2031.12
	MAT 300	61	5.45	332.45
	Resin	143	5.2	743.6

	Material	Qty for FAC 19 deck (kg/m^2 ,sheet) Rounded	Base price €/kg- €/sheet	Total cost
Permanent mold material	Gel coat	167	28.21	4711.07
	MAT 300	184	5.45	1002.8
	BIAX 0/90 600+MAT 255	672	6.96	4677.12
	Bonder	82	5.2	426.4
	Airex C70.55 60 kg/m^2	153	97.4	14902.2
	Resin	1155	5.2	6006
	MEKP hardener, can/ 1 kg	26	21.48	558.48
Total Basic material cost for permanent FAC 19 boat deck mold in €				**42,847**

Thus, the cost of the basic materials for making a permanent mold for FAC 19 boat deck is 42,847 Euro.

Table 4-8, Basic material cost for Temporary FAC 19 boat deck mold

	Material	Qty for FAC 19 deck (kg/m^2 ,sheet) Rounded	Base price €/kg- €/sheet	Total cost
Temporary female mold	Marine Plywood 18 mm	140 sheets	49.2	6888
	Marine Plywood 12 mm	35 sheets	82.29	2880.15
Total Basic material cost for Temporary FAC 19 boat deck mold in (€)				**9,768**

Thus, the cost of the basic materials for making a temporary mold for FAC 19 boat deck is 9,768 Euro.

In order to proportion the costs of the permanent mold to the temporary mold will calculate the quotient of the two costs

= permanent mold material cost / temporary mold material cost

=48,847/9,768=4.38≈5

This means choosing the appropriate method for creating a mold for FAC 19 boat deck in term of cost a permanent mold is created if the products are more than 4 products if the products are equal or less than 4 products the temporary mold is the best choice.

Chapter 5: RESULTS AND RESULTS DISCUSSION

5.1.Reverse engineering phase result and discussion

Each drawing in PDF format created with previous AutoCAD releases can be converted into editable drawing geometry using the PDFIMPORT command in AutoCAD 2017, and if the projection views are sufficient to make the 3D shape can get a very accurate model without taking additional measurement from the real product. Where applied that on FAC19 boat deck and the results were almost identical when compared with the existing product, figure 5-1 illustrates the comparison of width of sections ST-1 to ST-12 between the real deck and 3D model of FAC19 boat deck created by reverse engineering

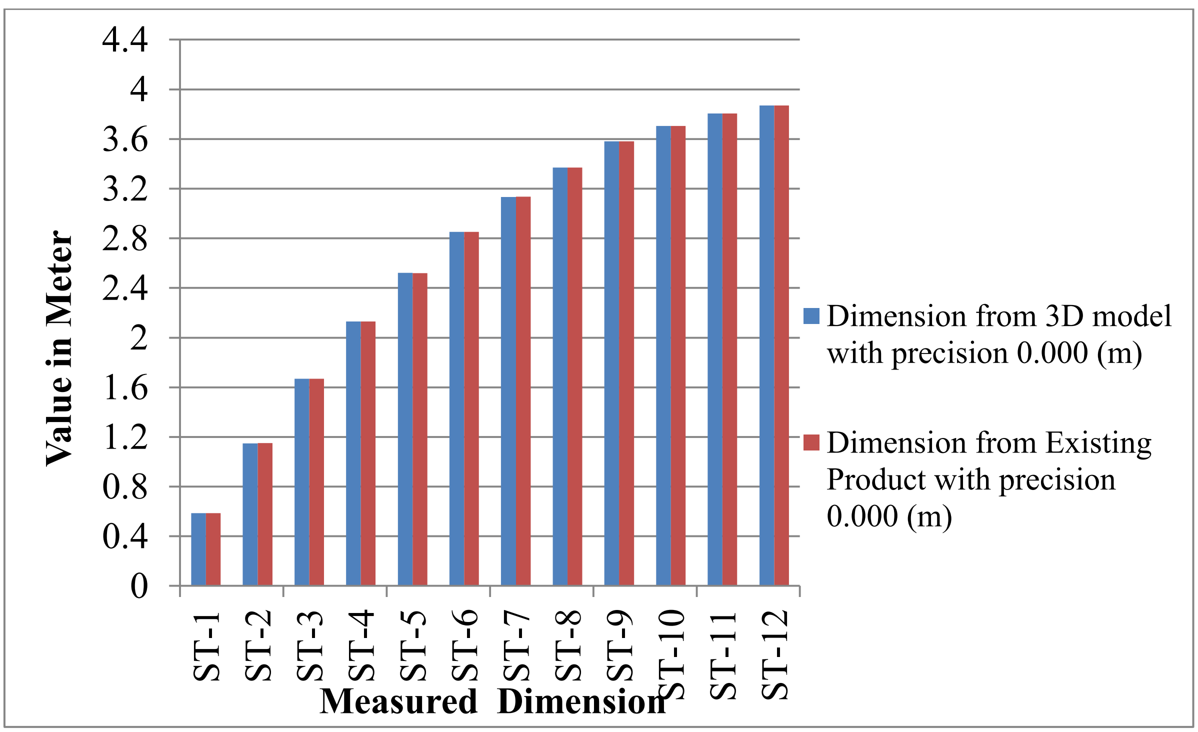


Figure 5-1, comparison of widtes at front of boat between 3d model and real product

And from the above gragh it is possible to note a percentage of conformity of the dimensions, its very high which makes us assure that the 3D model is identical to the real product, figure 5-2 shows the error percentage between the daimensions in table 3-3 of comparison between selected dimensions on the 3D model and existing product of FAC19 boat deck

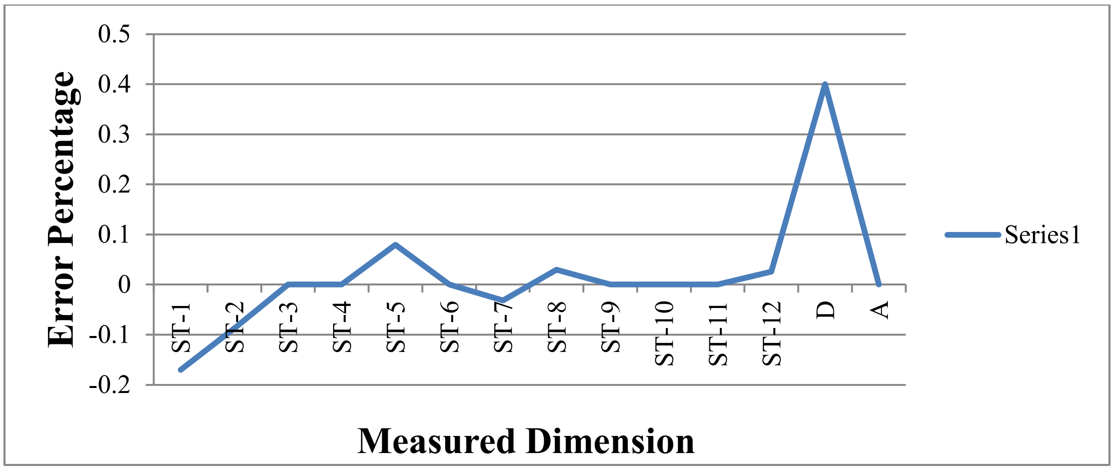


Figure 5-2, Errors percentage between selected dimensions on the 3D model and existing product of FAC19 boat deck

From graph Most of the errors rate ranges between-0.17036 to 0.08 %, but they are in millimeters 1-2 mm that may have resulted during manufacturing or during the manual measurement process. The largest error rate was in the width of the middle front window by 0.4 % or 3 mm and also it has no effect on the vision of the boat driver also it may result in the workshop which produce the window installed on the boat.

These percentages are almost negligible, and it can be said that the model is suitable for use in producing molds to produce FAC19 boat deck identical to the original product.

5.2.Mold building cost comparison phase result and discussion

The costs of creating a temporary mold and a permanent mold for the deck model studied in terms of the costs of the basic materials used in the manufacturing each of them

The cost of the basic materials for making a permanent mold for FAC 19 boat deck is 48,847 Euro.

The cost of the basic materials for making a temporary mold for FAC 19 boat deck is 9,768 Euro.

Figure 5-3 shows a chart showing the total cost of the basic material used to produce the permanent mold and temporary mold.

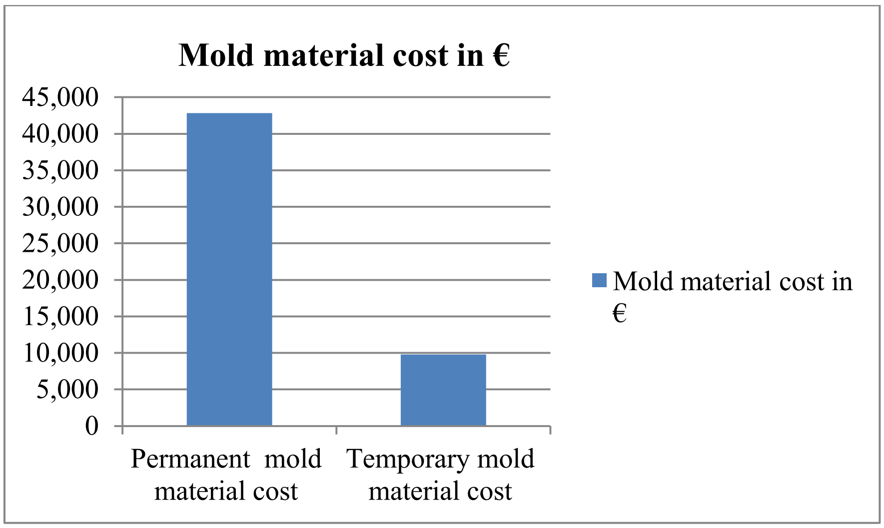


Figure 5-3, Permanent and Temporary mold material cost.

Proportion of the costs of the permanent mold to the temporary mold calculated

= permanent mold material cost / temporary mold material cost

=48,847/9,768=4.38≈5

This means choosing the appropriate method for creating a mold for FAC 19 boat deck in term of cost a permanent mold is created if the products are more than 4 products if the products are equal or less than 4 products the temporary mold is the best choice.

The mold surface affects three important areas of the molding process. First, the quality of the mold's cosmetic finish will be reproduced in every part. Regardless of whether it affects the physical performance of the part, every customer will judge your work by the surface quality. It is much easier to perform the steps one time on the mold surface than to touch-up every part after it is finished. Second, the mold surface affects the release characteristics of the mold. Any imperfections can contribute to adhesion problems. When a part sticks in a mold, extreme measures are often used to force the release. These can lead to broken flanges and mold edges, gouges on the surface itself. Finally, the mold surface coat is the protective barrier to the rest of the mold. Just as boats and other fiberglass structures can deteriorate due to exposure, a porous mold surface permits water, chemicals or other harmful agents to enter into the structural laminate below. (fibreglast, n.d.)

Where the quality of the mold's finish will be reproduced in every part the permanent mold for FAC 19 boat deck will qive a better qulity product than the temporary mold this is because the necessary precautions have been taken when building the mold starting by adding 2 mm clearance for covering the wood by mat and fishing the surfaces of the plug and applying tow layers of gelcoat on the mold.

As for the temporary mold a adistance for finishing the surface of the female mold were not added because its temporary and will be used to produce one product, The effort of finshing will be diverted to the product, so the product coming-out of the temperary mold will be much more less quality than the product comes-out from a paermanent mold.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Using the Reverse Engineering to Draw a Model for the FAC19 boat deck from the PDF drawing was highly successful because the views are sufficient to create the 3D wireframe and the use of the powerful software in surface creating and editing also the quality of the PDF file use for the reverisng engineering was quite good, these are the reasons for the success of reverse engineering for a modeling the FAC19 boat deck and the manual measurement tools verify that.

The Possible ways to produce a model of the deck is to create a a female mold whether it is a permanent or temporary mold, the difference between the two molds are in the durability , the number of products that can be produced from the mold without the need for much maintenance and the surface finish of the product comes-out of the mold.

Since the surface quality can be processed after molding in a temporary mold, the main factor in choosing between the two molds is the mold cost and the number of products required from it. Therefore, the production in the temporary mold was chosen after conducting a study of the basic material cost for each of the two molds, because what is required in this case is to produce one product for testing on it to install a weapon of a larger size to increase the armament strength of the FAC19 boat.

6.2.Recommendations

At the end of this study the following are recommended:

1. Using this AutoCAD and Rhinoceros for remodeling all available PDF boats drawing that has been used in Sudanese Navy and that for purpose of obtaining designs for boats in a 3D form to facilitate development and

modification of these boats.

2. The study recommended performing an analysis for the molds structures that were designed in this research to ensure their readiness and ability to be used in the production of FAC-19 boat deck.

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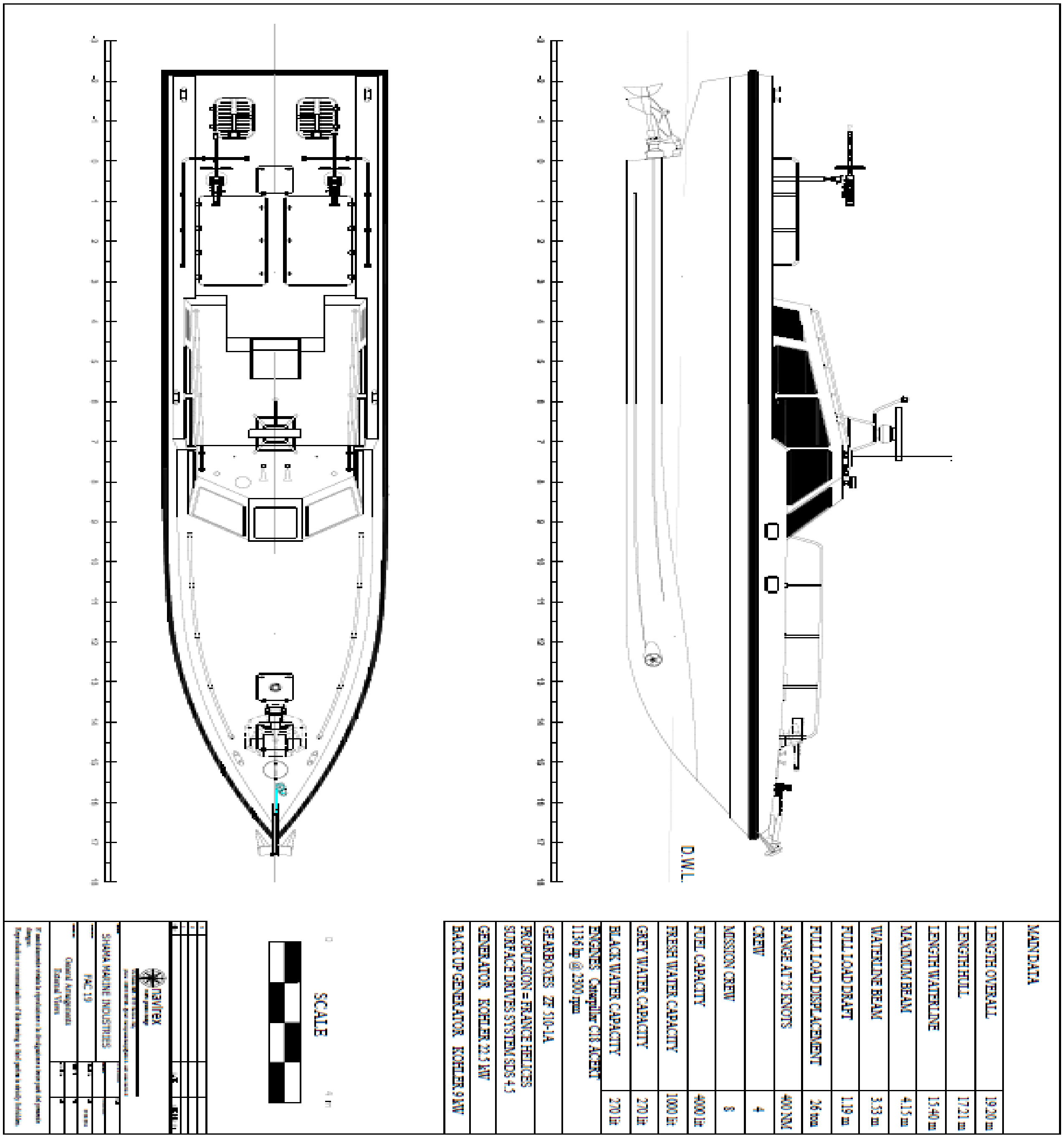
Appendixes:

Appendix A

FAC-19 boat general layout



Appendix B

FAC-19 lamination table

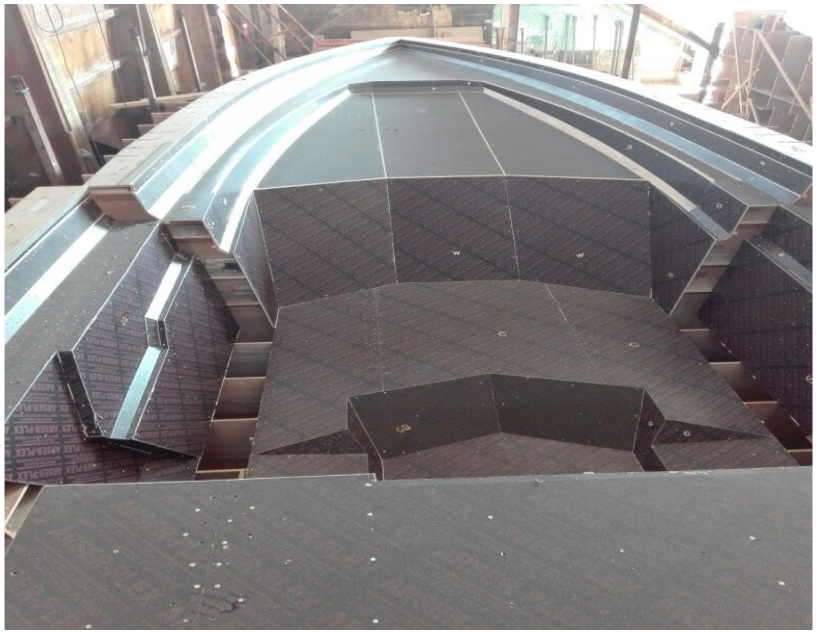
HULL LAMINATION TABLE											
LAYER N°	MATERIAL	ORIENT.	% REINF. (weight) - Wf -	LAYER WEIGHT (g/m2)	THICKNESS (mm)	DECK	ROOF	FLOOR	SIDES	STRINGER	FRAMES
0	GELCOAT	/	/	700	0.60	☐	☐	☐	☐	☐	☐
1	MAT 300	/	30	1000	0.70	☐	☐	☐	☐	☐	☐
2	MAT 300	/	30	1000	0.70	☐	☐	☐	☐	☐	☐
3	BIAX 0/90 600 + MAT 225	0/90°	46	1719	1.07	☐	☐	☐	☐	☐	☐
4	BIAX 0/90 600 + MAT 225	0/90°	46	1719	1.07	☐		☐			
5	Bonder	/	/	800	1.00	☐	☐	☐	☐		
6	Airex C70.55 60 kg/mc	/	/	1500	25.0	☐	☐	☐	☐		
6	Coremat 50 kg/mc	/	/	400	8.00					☐	
7	BIAX 0/90 600 + MAT 225	0/90°	46	1719	1.07	☐	☐	☐	☐	☐	☐
8	BIAX 0/90 600 + MAT 225	0/90°	46	1719	1.07	☐	☐	☐	☐	☐	☐
9	BIAX 0/90 600 + MAT 225	0/90°	46	1719	1.07	☐		☐			
11	MAT 300	/	30	1000	0.70	☐	☐	☐	☐	☐	☐
		Thickness external skin [mm]				3.54	2.47		2.47	2.47	2.47
		Thickness internal skin [mm]				3.91	2.84		2.84	2.84	2.84
		Thickness lamination [mm]				33.45	31.31		31.31	13.31	5.31
		Unitary weight per area [kg/m^2]				13.89	10.46		10.46	8.56	6.16
		Content in mass of reinforcement Gc [%]				43.30	41.40		41.40	39.40	41.40

NOTES:

- Thickness and Gc% without Gelcoat
- Weights with Gelcoat
- Verify sealant quantity is sufficient to fill holes in PVC

Appendix C

Temporary fiberglass boat mold sample.



Plywood temporary mold for FIC-15 (SHAMA MARINE -EGYPT)

Appendix D

Permanent fiberglass boat mold sample.

Permanent mold sample for RABCO 41'(boats-from-usa.com)